EVALUATION OF ANNUAL FORAGES FOR STOCKER AND FORAGE-FINISHING OPERATIONS

by

ELYSE MARIE FORD

(Under the Direction of Robert Lawton Stewart, Jr. and Alexander Stelzleni)

ABSTRACT

Two experiments were conducted to evaluate the use of annual forages in animal production systems. Experiment 1 evaluated the effects of cool season annual forages on animal production and forage productivity in stocker production systems. Forages systems evaluated were rye (R), rye plus ryegrass (RRG), rye plus wheat (RW), and rye plus crimson clover and arrowleaf clover (RC). Cattle grazing RRG produced a higher amount of BW gained in two out of three years. During years of cooler temperatures and abundant precipitation, RC was able to sustain a higher amount of BW gained. Experiment 2 studied the effects of warm season annual forages on animal production and meat quality in forage-finishing operations. Forage systems evaluated were pearl millet (PM), pearl millet plus crabgrass (PMCG), sorghum x sudangrass (SS), and brown-midrib sorghum x sudangrass (BMR). No differences were found for animal production. Cattle grazing treatments of SS had more yellow fat.

INDEX WORDS: Beef, Annual forages, Meat quality, Stocker production, Forage-finishing

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DEDICATION

This work is dedicated to Jessica and to Hadlie, who inspire me to strive for continual achievement and to try my best in all I do. Most importantly, this is dedicated to Ford, who has supported me and believed in me from the very beginning.

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TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

CHAPTER 1

INTRODUCTION

For several years, input prices have continued to increase for beef cattle producers. This has forced many cow/calf producers to exit the industry, or explore alternative management practices to maintain economic livelihood. The cost of traditional feedstuffs has continued to rise, with average US corn prices in 2012 reaching $6.78/bushel (USDA, 2013). Simultaneously, consumer demand has increased for locally grown, and forage finished beef, as supported by data from Lacy et al. (2007). Data from this study found grass-fed beef to be a characteristic deemed important by consumers, which is supported by a consumer willingness to pay up to 25% more for grass-finished beef when compared to beef finished on traditional feedstuffs. Considering the range of climate and geography, the Southeast allows for a variety of forages to be grown throughout the year, this presents an opportunity for beef producers to increase profitability through systems utilizing forages such as stockering and forage-finishing. However, the majority of beef producers will need to improve the quality of feed through the use of improved pasture, in order to optimize gains for these systems. Cherney and Allen (1995) found profits were highest when feed input from grazing is maximized while the use of stored forages or supplements is minimized. The successful use of forages in a production system will be able to provide sufficient nutrients that support high-levels of production, while being economically feasible for the producer. However, many grasses that are common to the southeastern United States are poorly suited to meet the high nutritional demands of growing cattle due to high concentrations of fiber components and slow rates of ruminal degradation (Ogden et al., 2006).

An important focus in the use of forages for production is finding high quality forage throughout the year, including during times of extreme climatic conditions such as drought and long periods of below-average temperatures (Burton, 1970). Forages with high nutritive values and yield potentials, such as warm- and cool-season annual forages, specifically those that are suited for the unpredictable climate of the southeast, must be investigated.

Cool season annual forages can provide high quality forage that traditionally have a longer production season and be higher in nutritive value than warm season perennial grasses (Ball et al., 2007). Additionally, economical BW gains can be achieved from animals grazing cool season annual forage combinations (Rankins and Prevatt, 2013; Beck et al., 2007c). With the combination of planting in early to mid-fall, and favorable weather, these forage systems can provide a source of grazing soon after many calves are weaned in early fall through early to late spring (Ball et al., 2007). Many cattle will require additional weight gain through the summer to reach the target BW for many forage-finishing programs. Warm season perennial grasses typically do not have the forage quality to achieve these gains, however warm season annuals have been found to have rapid establishment, produce leafy, high quality and palatable forages for grazing or hay production, and can produce large amounts of forage mass within a short period of time (Miller, 1984). However, the hot and humid summers of the Southeast present a challenge as the heat stress associated with this climate can cause a decrease in intake, efficiency and performance (Hahn, 1999). In addition to this obstacle, production through the summer months faces the challenge of warm season forages generally being less digestible than cool season forages (Ball et al., 2007).

The thesis research was divided into two experiments. The first experiment evaluated cool season forages for use in stocker production. Forage production and animal response was measured for rye (*Secale cereal*), rye plus wheat (*Triticum aestivum*), rye plus annual ryegrass (*Lolium multiforum*), and rye plus arrowleaf clover (*Trifolium vesiculosum*) and crimson clover (*Trifolium incarnatum*). Animal performance was measured as ADG and cumulative gain for cross-bred beef steers. Forage responses measured included weekly rising plate meter (RPM) measurements as well as bi-weekly hand clipping of 0.1 m^2 quadrants. Results from this study will allow producers to compare forage systems for stocker production in the Southeast. Additionally, these data will allow producers to apply the forage systems to specific production systems and needs.

The second experiment evaluated warm-season annual forages for finishing cattle and the effect on animal production and meat quality. The forages evaluated included pearl millet *(Pennisetum glaucum)*, pearl millet plus crabgrass *(Digitaria sanguinalis)*, brown-midrib sorghum-sudangrass (*Sorghum bicolor x S. bicolor ssp. drummondii*) and sorghum-sudangrass (*Sorghum bicolor x S. bicolor ssp. drummondii*). Animal response was measured through ADG and cumulative gain, as well as through ultrasound measurements. Carcass characteristics considered were carcass yield and quality characteristics, as well as objective and subjective color scores of fat and lean. Meat quality attributes studied included retail shelf-life evaluation of subjective and objective color, as well as lipid oxidation. Shelf-life evaluation of color is crucial to ensure minimal losses at the retail level, as discoloration may deter consumer purchase. Additionally, treatment influence on lipid oxidation is important as lipid oxidation is one of the major causes in meat quality deterioration (Jo and Ahn, 1998). Forages were also evaluated for proximate analysis, fatty acid analysis, slice-shear force, and sensory analysis. Focus on proximate analysis and fatty acids may provide key information on nutritional value as there has been much focus on lipid profiles, fat content and antioxidant properties of grass-finished beef when compared to grain finished beef (Daley et al., 2010). As forage-finished cattle have traditionally been associated with an increase in off-flavors (Melton et al., 1982; Mandell, et al., 1998; Bowling et al., 1978) and negative carcass characteristics (Bowling et al., 1978; Hendrick et al., 1983; Bidner et al., 1981) when compared to concentrate finished cattle, slice-shear force and sensory analysis can provide insight into quality and consumer appeal, aiming to minimize these characteristics. Results from this experiment will help assess the usefulness of warm season annual forages to meet production needs in a forage-finishing system, while evaluating the effects on carcass characteristics and meat quality in beef steers. This data aims to provide valuable information to producers which may lead to producing a higher gaining, higher quality product in an economic manner.

Data from these experiments are valuable from several standpoints. Producers can use data found from these experiments to make sound management decisions best suited for their operations. Additionally, scientists can use these data to further research in the meats industry, while working to optimize quality and sensory-attributes in grass-finished beef. In summary, this research is relevant to the agricultural industry as it provides valuable data related to forage-specific production and quality related aspects, as there is currently a deficient in knowledge in this area.

CHAPTER 2

REVIEW OF THE LITERATURE

Beef production is an important aspect of the economy within the southeastern United States. In Georgia alone, the beef industry consists of 1.02 million head of cattle and generated $445 million in revenue in 2012 (NASS, 2013). With the unpredictable prices of traditional feedstuffs and an increase in demand for forage finished beef, producers are seeking forages which can withstand the climate of the Southeast while providing adequate nutrient density to maintain gains in stockering and finishing operations.

Overview of Forages

Forage Types

Warm season annuals

Annual forages complete their lifecycle within one growing season, and only reproduce by seed. Warm season annuals such as pearl millet (*Pennisetum glaucum)*, crabgrass (*Digitaria sanguinalis)*, sorghum-sudangrass (*Sorghum bicolor x S. bicolor ssp. drummondii)* and brown midrib (BMR) sorghum-sudangrass (*Sorghum bicolor x S. bicolor ssp. drummondii*) are C_4 grasses which are productive in the spring and summer (Ball et al., 2007). These forages have been shown to have rapid establishment, high yields within a short period of time, and produce high quality and highly palatable forages for grazing or hay production (Miller, 1984). Under stressful conditions, these forages may contain nitrate and/or prussic acid concentrations, which may be harmful to livestock.

Pearl millet is a fast maturing, upright bunchgrass that generally grows from May to September, with the majority of production occurring within the first 6 to 8 weeks of growth (Miller, 1984). Pearl millet originated in Africa, evolving to tolerate high temperatures and periods of drought (Jain and Bal, 1997; Burton et al., 1972). Under ideal conditions, forage DM yield can be over 13,000 kg/ha, and can still produce approximately 9000 kg/ha under drought conditions. Pearl millet is adapted to both coarse- and medium-textured soils, and grows well in sandy soils. Additionally, it is tolerant of acidic soil, growing at a pH range of 5.5-7.5, and responds well to N fertilization (Ball et al., 2007; USDA, 2014a). Pearl millet is advantageous, as it does not produce prussic acid as other summer annual forages can and it can be grazed during drought conditions without risk of prussic acid poisoning. However, it may contain high nitrate levels. Pearl millet has also been found to be an excellent forage to utilize excess N built up in older pasture, as well as break up insect and disease cycles (Chamblee and Spooner, 1973).

Crabgrass is a prostrate forage with a fibrous root system, having a growth period of May through October (Ball et al., 2007), with the majority of growth occurring mid-June through early September (Andrae, 2002). Although crabgrass originated in southern Africa, it is not drought tolerant. Crabgrass is a valuable temporary summer grazing forage crop for livestock production, as it is tolerant of defoliation (Andrae, 2002). Crabgrass can produce large amounts of high quality forage, with pure stands yielding 6700-11,200 kg/ha when soil fertility is high and moisture is available (Andrae, 2002).

Sorghum-sudangrass hybrids are formed through the combination of cytoplasmic male-sterility of sorghum and pollen of sudangrass (Harvey, 1977), while BMR varieties of sorghum are produced through soaking sorghum seeds in diethyl sulfate (Oliver et al., 2005). As the sorghum family originated in Africa, these species are acclimated to arid climates and are able to go dormant during drought conditions and resume growth when the conditions pass (Miller, 1984). These forages have the highest yield potential of any other summer annual forage under proper growing conditions, with potential DM yields of 10,000-27,000 kg/ha. These forages are productive from June through September (Ball et al., 2007). Similar to pearl millet, sorghum-sudangrass hybrids can utilize excess N built up in soil from established pastures, as well as break up insect and disease cycles (Chamblee and Spooner, 1973). Sorghum-sudangrass and BMR sorghum-sudangrass are less tolerant of soils with low fertility and organic matter. These forages are more tolerant of drought conditions, but may accumulate high nitrate or prussic acid levels causing toxicity under stressful conditions (Ball et al., 2007).

Much interest has come about comparing BMR and traditional varieties of crops, as the brown midrib (BMR) gene has shown to decrease lignin concentration in plants. This naturally occurring mutation contributes to improved fiber digestion in the rumen (Sattler et al., 2010), as lignin interferes with the digestion of cell-wall polysaccharides and acts as a physical barrier to microbial enzymes (Moore and Jung, 2001). The term 'brown midrib' comes from the characteristic reddish-brown to tan colored midrib of the leaf blade, as compared to the characteristics green midrib of traditional varieties. Additionally, the characteristic red-brown color can also be seen in the roots and stalks of plants with the brown midrib gene (Sattler et al., 2010). However, the brown midrib mutation has shown to result in decreased DM yields and to be less tolerant of grazing than non-brown midrib varieties (Pedersen et al., 2005).

Cool season annuals

Cool season annual grasses such as cereal rye (*Secale cereale*) annual ryegrass (*Lolium multiflorum*), and wheat (*Triticum aestivum*) are C_3 grasses that generally have higher nutritive value than warm season (C_4) grasses (Ball et al., 2007). This can be attributed to the leaf anatomical characteristics associated with C_4 photosynthesis, which have twice as many veins per unit of leaf width than C_3 grasses. This results in an increase in the amount of tissues which have thickened secondary wall, such as vascular bundles, parenchyma bundle sheaths, epidermis and sclerenchyma strands, which are the least digestible portion of grass leaves (Brown, 1999). Cool-season annual forages are commonly planted in the autumn, with a wide range of productivity and variation based on species. Cool season annual forages may be established in a prepared seedbed or overseeded in permanent pastures. While cool season annual forages provide high quality forage when warm season forages are dormant, unpredictable climatic conditions may greatly affect the growth of these grasses, affecting each species differently (Ball et al., 2007), which can create a wide range of variability in forage performance.

Cereal rye is a drought-tolerant and winter-hardy annual bunchgrass, which is more tolerant of acidic soil than other winter annual forages (Ball et al., 2007). Rye grows best in light loams or sandy soils, but it also grows well in clay soils (USDA 2014b). Rye produces 5,000-7,000 kg DM/ha annually, producing more forage mass in late winter when compared to other small grains. However, rye is earlier maturing than other winter annuals. Due to these traits, rye is well suited for early grazing or for use on cropland that will be used in spring and summer row crop production (Ball et al., 2007). However, forage quality rapidly declines as rye enters the reproductive stage exhibiting decreased leaf production, when a greater portion of forage mass is associated with its fibrous stem. Rye can also be used to scavenge nitrogen, prevent erosion, and suppress weeds by producing alleopathic chemicals (USDA, 2014b).

Annual ryegrass is a bunchgrass with high palatability, seedling vigor, and tolerance to wet, poorly-drained soil. Additionally, ryegrass is a high quality forage which can provide 70% TDN and 18% CP in the late vegetative stage, and 64% TDN and 10-16% CP in the pre-boot of seedhead development (Dhaliwal et al, 2009; USDA, 2014c; Ball et al, 2007). Ryegrass has a greater percentage of its growth in late spring when compared to other small-grain based pastures such as rye, oat and wheat, thereby potentially extending the grazing season (Beck et al., 2007c). Additionally ryegrass can produce approximately 12,000 kg DM/ha annually.

Wheat is a winter-hardy annual bunchgrass, which can provide forage from late fall and early winter through spring. Wheat establishes well in mixtures of clovers, ryegrass, or other small grains. When grown alone, wheat can produce 5,000 - 8,000 kg/ha DM (Ditsch and Bitzer, 2005), although yields in the Southeast may be nearer to 6700 kg/ha (Hancock et al., 2011). Wheat grows well in low moisture areas, at a pH range of 5.5 to 8.0, and is adapted to fine-, medium-, and coarse-textured soils (USDA, 2014d).

Legumes such as arrowleaf clover (*Trifolium vesiculosum*) and crimson clover (*Trifolium incarnatum*) are dicots, producing seed in a pod, and have the majority of their growth in late winter and early spring. Legumes are advantageous as they have the ability to utilize atmospheric nitrogen through the interaction of *Rhizobium* bacteria and nodules found on the plants root. Additionally, legumes are among the highest quality forage available (Ball et al., 2007).

Arrowleaf clover is a late season winter annual legume, which produces predominately white flowers, with pink- and purple-tipped flower heads (Ball et al., 2007). Arrowleaf clover is not adapted to wet soils, and is not tolerant of low fertility or soil acidity, with an optimum pH of 5.8-6.5 (Ball et al., 2007). Arrowleaf clover is a reseeding legume, and grows from March to early June, with the majority of its growth occurring between April and May. Arrowleaf has an annual yield of approximately 3,900 kg DM/ha (Ball et al., 2007), and produces seeds in the late spring and early summer producing seed yields of 220-330 kg/ha with approximately 75% hard seed. This characteristic allows it to maintain long term stands if allowed to reseed and may produce volunteer stands for up to five years (Ball et al., 2007; USDA, 2014e). Additionally, the incorporation of arrowleaf clover may extend the grazing season since it is later maturing (Hoveland and Evers, 1995).

Crimson clover is an early maturing winter annual legume that produces crimson flowers, and may be planted alone or mixed with small grains or other winter annual forages (USDA, 2014f). Crimson clover is tolerant of slightly acidic soils, with an optimum pH of 6.0-7.0, and does not tolerate poorly drained soils (USDA, 2014f). Production of crimson clover occurs in March through April, and can produce approximately 3,900 kg DM/ha (Ball et al., 2007; USDA, 2014f). Crimson clover grows best on well-drained fertile loamy soils of moderate acidity (pH 5.5 to 7.0), and is adapted to sandy and clay soils (USDA, 2014f).

The incorporation of clovers or other legumes into an annual grazing system may extend the grazing system (Sleugh et al., 2000), increase total forage yield, and can increase the nutritive value for grazing livestock (Giambalvo et al., 2011; Dierking et al., 2010b). Additionally, grass-legume mixtures show an increase in efficiency for light, water, and nutrient utilization when compared to monocultures (Hauggard-Nielsen and Jensen, 2005; Corre-Hellou et al., 2006). These traits may increase yield stability and improve sustainability by reducing incidence of disease, pests, and weeds, as well as increase future crop yields (Anil et al., 1998). Additionally, the use of clovers and other legumes may reduce the need for conventional N fertilizer application (Butler et al., 2012; Anil et al., 1998). Giambalvo et al. (2011) reported that an increase in proximity of legume and grass roots increased the likelihood of N transfer between the species. Grass production is dependent on N, and the high cost of N fertilizer can greatly affect producer operations. The incorporation of clovers may provide an alternate N source, alleviating production costs and potentially increasing profits. Furthermore, Butler et al. (2012) showed that were no differences between the use of legumes and traditional N for use in fertilization in terms of forage mass, forage allowance, ADG, or total gains in the Southern Great Plains. However, they also showed that incorporating legumes as a substitute for N fertilizer did not affect expected net return (Butler et al., 2012).

Nutritive Value

Typical summer grazing programs in the southeastern United States consist almost exclusively of warm-season perennial grasses, which decline in nutritive value throughout the summer (Redmon et al., 2003). However, warm-season annual forages have been shown to be viable options for use in improved forage systems. An evaluation of the nutritive value of 19 warm-season grasses (including crabgrass and a variety of other warm-season species) have been shown to have N concentrations between 1.09 and 3.38% (Coblentz et al., 2004).

Crabgrass is an annual forage which has high nutritive value and palatability (Blount et al., 2003; Dalyrmple et al., 1999). Ogden et al. (2005) reported crabgrass had greater DM and NDF digestion rates and less fiber content than common bermudagrass during a 7-wk study. Nitrogen concentrations in whole-plant samples of crabgrass were found to decrease linearly across a 7-week sampling period, decreasing from 3.36% DM to 2.55% DM (Ogden et al., 2006). An evaluation of crabgrass composition evaluated nutritive value on 21 d, 35 d, and 49 d, finding a linear decrease in CP and TDN. Values for CP were 15.6, 14.3, and 11.0 % DM, respectively, with TDN values of 62.6, 59.1 and 54.8% DM. Additionally, NDF and ADF increased linearly, with values of 61.3, 66.6, and 69.8% DM and 35.7, 38.9, and 42.7% DM, respectively (Ogden et al., 2006; Beck et al., 2007b). When comparing forages, crabgrass was found to have a greater mean effective ruminal in situ disappearance (85.4% of N) when compared to alfalfa, bermudagrass, or orchardgrass hay by 2.1, 13.1 and 9.4 percentage units of N, respectively (Ogden et al., 2006). Comparing effective disappearance of NDIN, crabgrass was found to have a mean disappearance rate of 0.110 %/h. This rate was faster ($P < 0.001$) than common bermudagrass hay (0.072 %/h) and orchardgrass (0.098 %/h) hay, and slower than of alfalfa hay ($P < 0.001$; 0.150 %/h). Effective NDIN ruminal disappearance of crabgrass was 73.4 to 70.8% across sampling dates, with a mean effective disappearance of 72.0% which was greater than alfalfa hay (50.5%) and bermudagrass hay (69.0%), and similar to orchardgrass hay, which was taken from a second cutting and was entirely vegetative regrowth (72.1%). Crabgrass exhibited a mean fraction of immediately digestible N of 54.6%, which was greater than alfalfa, bermudagrass and orchardgrass (43.4% of N, 31.6% of N, and 27.1 % of N, respectively) and may be indicative of inefficiency in the rumen due to rapid conversion to ammonia (Ogden et al., 2006).

Schmidt el al. (2013) evaluated alfalfa, a mix of common and Coastal bermudagrass, chicory, cowpea, and pearl millet, and found bermudagrass had the highest percentage of NDF and ADF (65.48% and 27.96%, respectively), followed by pearl millet (49.83% and 22.89%), which was higher than the remaining forages. Pearl millet contained 22.79% CP, which was intermediate amongst the other forages, and 2.87% fatty acids, which was the similar to chicory and higher than the remaining forages.

Sorghum-sudangrass hybrids were found to have digestibility comparable to perennial grasses. However, low voluntary DMI resulted in low digestible energy consumption. When harvested 52 d after planting, chopped to 1.2 cm lengths, and force dried at 50°C for 48 h, sorghum-sudangrass had a CP of approximately 20%, compared to CP concentrations of approximately 10% when harvested at 85 d after planting. Additionally, ADF, cellulose, and cell-wall constituents increased slightly on a percentage basis until 76 d after planting, after which the percentage increased sharply. Forage quality maintained digestibility during the first 61 d after planting (during the vegetative state) however there was a decline in digestibility following that time. In subsequent harvests after 61 d after planting, the rates of digestibility of cellulose, acid detergent fiber, and cell-wall constituents declined between 0.50-0.65 percent per day (Ademosum et al., 1968).

In comparing the nutritive value of brown midrib and traditional varieties of sorghum x sudangrass (Redlan x Greenleaf, Redlan x Piper, and their corresponding BMR varieties), BMR varieties had higher ruminal digestibility of NDF, ADF, and calculated cellulose than traditional varieties, as well as, a greater total tract digestibility of cellulose (Wedig et al., 1988). Additionally, in an evaluation of BMR- and traditional varieties of sorghum for ensiling properties, Miron et al. (2007) reported fresh-chopped BMR forage sorghum was found to have higher amounts of hemicellulose and lower amounts of lignin and cellulose than a traditional variety of forage sorghum. The *in vitro* digestibility fraction of DM was higher ($P < 0.05$) for the BMR variety than the non-BMR variety (0.70 vs. 0.66, respectively). Additionally, the *in vitro* digestibility fraction of NDF was higher ($P < 0.05$) for the BMR variety of sorghum plants when compared to the non-BMR variety (0.58 vs. 0.51, respectively; Miron et al., 2007).

Comparisons of BMR and traditional varieties of sorghum x sudangrass hybrids found BMR varieties to have a rate of disappearance that was 2.9 to 4.1 percentage units greater than normal varieties for DM immediately soluble, and a higher non-digestible fraction of DM for non-BMR varieties than BMR varieties. The effective percent of DM degradability (calculated as: A fraction + {B fraction x [Kd/(Kd + Kp)]} of OM, with Kp being the ruminal particulate passage rate at an assumed 3.5%/h and Kd being the disappearance rate) of non-BMR varieties was less than BMR varieties across all dates forage samples were obtained (Ogden et al., 2005). Additionally, the rate of NDF disappearance was more rapid for BMR hybrids than traditional varieties (3.54 and 3.98%/h, respectively), with effective NDF degradability of non-BMR being 3 percentage units lower than BMR (Beck et al., 2007a). Ledgerwood et al. (2009) found pelleted BMR sudangrass hay to be higher in organic matter, digestibility of organic matter, digestibility of DM, and lower in nitrogen, acid detergent fiber, cellulose, and lignin when compared to a pelleted non-BMR variety. While the lignin content of pelleted BMR sudangrass was not found to be lower than non-BMR varieties, BMR sudangrass hay was found to be lower in lignin than non-BMR varieties. No differences in lignin may be seen after pelleting as the mechanical process of pelleting ruptures plant cells, decreasing the negative impact of lignified walls and allowing bacteria access to previously unavailable cell wall polysaccharides (Paulson et al., 2008). Additionally, *in vitro* true digestibility of neutral detergent fiber was higher for BMR varieties when compared to non-BMR varieties at 24, 48 and 72 h of fermentation (Ledgerwood et al., 2009).

Legumes characteristically have a higher nutritive value than grasses at similar growth stages (Butler et al., 2012; Sleugh, et al., 2000), therefore the incorporation of legumes into grass pastures can improve forage digestibility by grazing animals (Sleugh et al., 2000). Crimson clover can exceed 25% crude protein in up to full bloom and may contain 12-14% CP at full bloom (Ball et al., 2007; USDA, 2014f).

Animal Performance

Production System

Comparing cool-season annual forage systems combining oats (*Avena sativa*) and ryegrass, rye and ryegrass, and oat plus rye and ryegrass, Mullenix et al. (2012) found steers grazing rye/ryegrass mixtures had lower ADG when compared to oats and ryegrass or oats plus rye plus ryegrass (1.13 kg, 1.38 kg, 1.26 kg, respectively; SE = 0.05). However, there was no difference in the amount of grazing days between the forage combinations. Additionally, during a 3-yr, grazing trial Coffey et al. (2002) found no benefit in the addition of rye to ryegrass in stocker calf production. Beck et al. (2005) also experimentally grazed steers on cool season annual forages alone or in combination. Across years, steers grazing rye during the spring gained 1.11 kg/d (SE = 0.05), compared to oats (1.02 kg/d), annual ryegrass (1.27 kg/d), soft-red winter wheat (1.27 kg/d), or combinations of rye plus ryegrass (1.32 kg/d), wheat plus rye (1.17 kg/d), wheat plus ryegrass (1.24 kg/d), or wheat plus rye and ryegrass (1.12 kg/d). In comparing cool-season forage systems, Beck et al. (2007c) found the incorporation of ryegrass with small grains (oats, rye or wheat) increased grazing period (d/ha; 600 d compared to 516 d), increased BW gain/ha (514 kg vs. 354 kg), and increased net return/ha ($210.99 compared to $67.60). The authors suggested interseeding ryegrass with small grains could produce the highest profitability, BW gain/ha, and days of grazing, indicating ryegrass can be an integral component of a grazing program. Focusing on the use of ryegrass in grazing systems, Beck et al. (2005) found steers grazing rye plus ryegrass in the spring had an ADG of 1.32 kg/ha over a three-year period in Arkansas. No differences were found in ADG and BW gain per ha for calves grazing wheat, ryegrass, rye plus ryegrass, and wheat plus ryegrass.

In a subsequent three-year study, Beck et al. (2008) compared the effects of steers grazing rye plus wheat to steers grazing tall fescue (both novel endophyte and endemic endophyte), as well as annual ryegrass. Steers grazing rye plus wheat showed an ADG during spring grazing of 0.84 kg/d, 0.89 kg/d, and 0.90 kg/d (SE = 0.05) during spring grazing during the three-year study. Data for steers grazing treatments of annual ryegrass was reported for two years of the study, reporting an ADG of 1.12 kg/h and 1.10 kg/h (SE = 0.05). Throughout the three-year study, the forage combination of wheat plus rye yielded 590 grazing d/ha, 440 grazing d/ha and 687 grazing d/ha, respectively. Additionally, annual ryegrass yielded 635 grazing d/ha and 751 grazing d/ha for the two years data was recorded (Beck et al., 2008).

The use of BMR varieties has been reported in other production systems. When BMR and normal varieties of corn silage with similar NDF (60%) were fed to lambs, the BMR variety was found to be 10% more digestible than the normal variety silage, and had 20% greater NDF digestibility. Brown midrib silage fed lambs were also found to have higher voluntary DMI (Muller et al., 1972). Lactating cows fed silage from BMR sorghum had similar performance to corn and alfalfa-based silages, and had improved performance when fed a non-BMR variety of sorghum silage (Grant et al., 1995). Additionally, the use of pearl millet as an improved forage for grazing has been conducted previously, with Harvey and Burns (1988) reporting an ADG of 1.09 and 1.05 kg/d in calves when allowed to creep graze pearl millet.

Forage Finishing

Dating back to the 1930s and 1940s, forage-finished cattle has been of interest to researchers and producers (Brown, 1954). However, as land use became more focused on intensively producing both livestock and crops, grain and other concentrates became incorporated in cattle feed systems. This introduction resulted in a shorter beef production period and a higher plane of nutrition, typically resulting in a tenderer product with more intramuscular fat (Bidner et al., 1981; Crouse et al., 1984). Further attempts to reduce cattle and beef production costs through increasing efficiencies in the production and supply chain gave way to the feedlot system (Mathews and Johnson, 2013). However, as more consumers are becoming interested in forage-fed beef (Romig, 2013), opportunities exist for producers to meet the needs of this niche market, warranting a return to research on forage-finishing cattle. Currently, livestock production systems in the Southeast are primarily cow-calf enterprises (Allen, et al., 1996; Boykin et al, 1980), with a limited number of cattle being retained for finishing and being harvested regionally (Boykin et al., 1980). As the temperate climate of the Southeast allows for the growth of forage production throughout most of the year, this creates an opportunity for producers in this region to finish cattle on forage without using appreciable amounts of stored feeds take advantage of this niche market opportunity (Rankins, Jr. and Prevatt, 2013).

In addition to alleviating the costs of feedstuffs, there has been an increase in consumer and restaurateur interest in locally produced products (Maynard, et al., 2003; Darby et al, 2006), a consumer willingness to pay for local and grass-finished product (Lacy et al, 2007; Darby, et al., 2006), as well as a general growing interest in grass-fed or pasture-finished beef (Lacy et al., 2007). This growing interest in grass-fed or pasture-finished beef may be attributed to perceived health benefits of forage-finished beef. Forage-finished beef has been found to have a more desirable saturated fatty acid (SFA) lipid profile, containing more C18:0 cholesterol neutral SFA, while also containing less C14:0 and C 16:0, which are cholesterol elevating SFA (Realini et al., 2004; Leheska et al., 2008). Forage-finished beef has also been found to have a lower n-6:n-3 ratio (Leheska et al., 2008; Realini et al., 2004; Daley et al., 2010), which is more preferable from a human cardiac health viewpoint (Daley et al., 2010; Kritchevsky et al., 2002). Grass-finished beef has also been found to be higher in precursors for Vitamin E, Vitamin A, and cancer fighting antioxidants (Daley et al., 2010; Dunne et al., 2009). Additionally, grass-finished ruminants have been shown to produce two-to-three times more conjugated linoleic acid (CLA) than ruminants finished on grain diets (Daley et al., 2010). Studies have shown CLA attributes to the reduction of carcinogenesis, atherosclerosis, and the onset of diabetes (Ip et al., 2002; Daley et al., 2010; Kritchevsky et al., 2002). While these findings suggest finishing cattle on pasture may be of interest to Southeastern producers, forage-finished beef has been discriminated against due to production, yield, quality, and sensory differences when compared to concentrate-fed cattle (Bowling et al., 1977; Brown, 1954; Schroeder et al., 1980; Hedrick et al., 1983).

Animal Production

Over the years, numerous studies have compared the animal performance and yields produced from concentrate and forage finished cattle. A comparison of concentrated fed and forage finished cattle found cattle fed concentrate had greater ADG than cattle fed strictly forage based diets (Bidner et al., 1981, 1986; Mandell et al., 1997; French et al., 2001; Roberts et al., 2009).

While there is little data comparing animal performance of cattle finishing on specific forages, a few studies have been conducted. Short term (40 d) forage finishing trials conducted by Duckett et al. (2013) evaluated the use of pearl millet for forage finishing, and found steers finished on pearl millet produced greater gains (1.61 kg/d) when compared to steers grazing mixed pastures and alfalfa (1.11 and 1.15 kg/d, respectively; SE = 0.13). During this study, Duckett et al. (2013) also found no differences between treatment for hot carcass weight (HCW), kidney, pelvic, heart (KPH) fat percent, fat thickness, or rib-eye area for cattle grazing treatments of mixed pastures, alfalfa, or pearl millet. However, in a comparison of alfalfa, bermudagrass, chicory, cowpea and pearl millet, Schmidt el al. (2013) reported the average daily gain for steers was greatest for those grazing alfalfa (1.28 kg/d) and chicory (1.13 kg/d), and least for those grazing on bermudagrass (0.76 kg/d), pearl millet (0.56 kg/d) and cowpea (0.88 kg/d). The lower ADG reported for cattle grazing treatments of pearl millet may be due to the higher nutritive quality of pearl millet in the immature state, which declined throughout the grazing season. Additionally, drought conditions during the 2007 and 2008 summer grazing season in Anderson, South Carolina may have affected forage growth, and contributed to the low ADG of cattle grazing pearl millet (Schmidt et al., 2013).

Carcass Yield and Characteristics

Improvement in carcass characteristics and meat quality are important to producers as emphasis is placed on consistently providing a high quality product (Peña et al., 2014; Sahin et al., 2008). Ultrasonography may be of use to producers to assess quality and yield predictions, as it has been shown to provide accurate, fast, and affordable determinations of beef carcass composition and quality (Lambe et al., 2010; Houghton and Turlington, 1992). Additionally, ultrasonography is a non-invasive technique, with serial ultrasound measurements creating an opportunity to assess carcass attributes on live animals (Brethour, 2000; Peña et al., 2014; Wall et al., 2004). Quality and yield attributes which can be evaluated using ultrasound measurements are subcutaneous fat thickness between the 12^{th} and 13^{th} ribs, *longissimus dorsi* muscle area, rump fat thickness, and intramuscular fat, or marbling, within the *longissimus dorsi* (Wall et al., 2004). A comparison of carcass characteristics found cattle fed concentrates had heavier live weight (Leheska et al., 2008; Mandell et al., 1998), as well as greater adjusted fat thickness, KPH, and calculated yield grade when compared to forage finished cattle (Garmyn et al., 2010; Crouse et al., 1984). Additionally, when finished to similar time endpoints, forage-finished cattle have been found to have lighter HCW when compared to concentrate fed cattle (Crouse et al., 1984; Duckett et al., 2007; Bennet et al., 1995; Mandell 1984).

The increased plane of nutrition associated with concentrate fed cattle allows for greater marbling deposition resulting in greater marbling scores (Garmyn et al., 2010; Reagan et al., 1977; Leheska et al., 2008; Bidner et al., 1981; Duckett et al., 2007) and quality grades (Reagan et al., 1977). In addition to an increase in marbling, differences between concentrate and grass-finished cattle can be seen in the subcutaneous fat color. Carcasses from grass-finished cattle have been found to have more yellow fat than concentrate finished cattle (Leheska et al., 2008; Crouse et al., 1984; Bidner et al., 1976). This is due to greater amounts of β-carotene and other carotenoid pigments found in forages, which can be ingested and deposited in adipose tissue (Leheska et al., 2008; Strachan et al., 1993; Yang et al., 1992). Although excessive yellowness in fat color is considered undesirable in most beef markets, some markets regard yellow fat as indicators of a healthier product (Dunne et al., 2009). Additionally, grass-finished beef has been associated with darker-colored lean tissue when compared to concentrate fed cattle (Bidner et al., 1981; Crouse et al., 1984). Myoglobin is known to be the primary pigment in meat color, and concentrations are known to increase with age (Lawrie and Ledward, 2006). This factor, combined with the longer time of production when compared to concentrate finished cattle may account for the darker color associated with meat from grass-finished cattle. Leheska et al. (2008) found no difference in lean color between grass and grain-finished cattle harvested between 16 – 30 mo (mean 23 mo), while Bidner et al. (1981) and Crouse et al. (1984) found grass-finished cattle to have darker lean color, coarser texture, lower firmness scores and greater lean maturity scores. Comparison of carcasses of grass- and concentrate-fed cattle by Crouse et al. (1984) occurred when cattle from both treatments reached 22 mo of age. While all cattle in the study of Bidner et al. (1981) began the study at approximately 11 mo of age, cattle fed forage required an extra 160 d when compared to cattle fed any ratio of grain to meet the desired weight of 476 kg. Dunne et al. (2006) found concentrate finished cattle had a greater '*L*' value (lighter in color), as well as had lower heme pigment concentration than grass finished cattle. Duckett et al. (2013) found no differences between treatment in a short term (40 d) forage finishing trial for fat color or lean color for cattle grazing treatments of mixed pastures, alfalfa, or pearl millet.

Meat Sensory Attributes

In beef, palatability depends on tenderness, juiciness, and flavor attributes (Hocquette et al., 2014; Wilson et al., 1954; Jeremiah et al., 2003b). As cattle finished on forage take longer to reach similar weights or compositional endpoints than concentrate-fed cattle due to lower energy intake on forage, grass-finished cattle can be one year older or more than concentrate fed cattle at time of slaughter (Fontenot et al., 1985; Romig, 2013). This age difference affects product tenderness as collagen, a main connective tissue, develops more cross-links in muscle over time. As the degree of collagen cross-link formation increases, product tenderness decreases, explaining why meat from older animals is generally tougher than meat from younger animals (Jeremiah et al., 2003a). Subjective methods to evaluate tenderness consist of a trained sensory panel, while Warner-Bratzler shear force and slice-shear force provide objective evaluation (Damez and Clerjon, 2008). Shackelford et al. (1999) found slice-shear force measurements to be more strongly correlated (r = -0.82) to sensory panelist rating of tenderness than to Warner-Bratzler shear force measurements (r = -0.77), although both methods of evaluation are highly related. Additionally, Wheeler et al. (2002) reported slice-shear force can accurately identify beef as tender. When comparing grass-finished and concentrate finished cattle, cattle finished on grain had lower Warner-Bratzler shear force values and more tender sensory tenderness ratings than grass-finished cattle (Garmyn et al., 2010), while Bidner et al. (1981) and Crouse et al. (1984) found no differences in Warner-Bratzler shear values or consumer evaluations from grass-finished cattle when compared to grain finished cattle when harvested at a similar endpoint. Bowling et al. (1977) compared grass and grain fed cattle through harvesting steers at similar maturity and marbling scores (one forage-finished and one grain finished steer, of essentially identical USDA quality grade), but reported differences in external fat. These researchers also showed higher quantities of connective tissue, higher shear force values and decreased tenderness in meat from grass-fed cattle.

In addition to tenderness, flavor profiles and juiciness are important to consumer preferences. Meat flavor may be dependent on cattle breed, type and maturity of forage, and fat content and marbling score (Van Elswyk et al., 2014). Cattle finished on diets of grass or silage have been found to rate lower in beef flavor (Mandell et al., 1998; Duckett et al., 2007), have an increase in off-flavors (Melton et al., 1982c; Duckett et al., 2007), and graded lower in sensory panel ratings for flavor desirability when compared to concentrate finished cattle (Bowling et al., 1978; Schroeder et al., 1980). Steaks from cattle grazing on pearl millet and alfalfa were found to rate higher in beef flavor intensity than mixed pastures when forage finished for a 40 d period (Duckett et al., 2013). Sitz et al. (2005) reported grass-fed Canadian and Australian strip-steaks were found to have lower ratings of beef flavor and overall acceptability when compared to strip-steaks from domestic, concentrate fed cattle. However, Crouse et al. (1984) found no difference in sensory traits between cattle fed diets of pasture or corn plus corn-silage when fed to a back fat thickness of at least 0.79 cm. As species flavor originates from fatty tissue (Melton, 1990), it can be speculated that the decreased amount of subcutaneous and intramuscular fat can contribute to the decreased beef flavor in grass-finished beef when compared to concentrate finished beef. Some studies have found meat from concentrate-finished cattle to be juicier when compared to grass-finished product (Sitz et al., 2005; Schroeder et al., 1980), while others found no differences in perceived juiciness between treatments (Duckett et al., 2013; Reagan et al., 1977; Garmyn et al., 2010; Mandell et al., 1998). Differences in amounts of intramuscular fat, or marbling, may contribute to these differences in perceived juiciness.

Shelf Life

Product shelf life is considered the length of time the food product remains acceptable under expected conditions of distribution, storage and display (Gyesley, 1991). As meat has high water activity and high concentrations of readily available nutrients, it is well suited to support the growth of microbes. Microbial growth results in off-odors, off-tastes, texture changes, and slime formations. Additional biochemical reactions such as lipid oxidation can contribute to further discoloration and meat rancidity. Degree of spoilage is a subjective determination by the consumer, and can be affected by acuity in the senses, intensity of perceived change, and cooking traditions. Spoilage is the process by which a product deteriorates to a point where it is considered inedible by humans, or has a reduced quality, causing the product to be undesirable for sale or consumption (Sun and Holley, 2012). Meat spoilage is usually characterized by two processes. The first process is bacterial growth and metabolism, which results in objectionable compounds that form gas, off-odors, and slime.

The second process characteristic to meat spoilage is the oxidation of lipids and pigments (Sun and Holley, 2012). A study comparing finishing treatments of concentrate or grass in genetically related heifers found concentrate-finished cattle had greater lipid oxidation (as measured by thiobarbituric acid-reactive substances; TBARS) than grass-finished cattle on d 0 of simulated retail display. However following 7 d of retail display, there was no difference in TBARS values between treatments (Garmyn et al., 2010).

The oxidation of lipids and pigments can result in undesirable flavors and discoloration (Sun and Holley, 2012). In the anaerobic environment, such as found in deep muscle, myoglobin forms deoxymyoglobin and is purple. Upon exposure to air, myoglobin oxidizes to form oxymyoglobin, which forms the bright-red color traditionally associated with fresh meat. At lower partial pressures of oxygen, myoglobin also oxidizes to form metmyoglobin (Muir et al., 1998). Metmyoglobin can be seen as a noticeable brown color when approximately 60% of myoglobin exists in this form, and is perceived as unattractive by consumers (Lawrie and Ledward, 2006; Muir et al., 1998). In shelf-life studies evaluating color, Schroeder et al. (1980) found lean tissue from cattle fed forage based diets to be darker at the beginning of the study. This darker lean tissue may be attributed to increasing myoglobin content with increasing age of cattle (Lawrie and Ledward, 2006) and the longer finishing time associated with forage-finished cattle. Schroeder et al. (1980) also found lean tissue from forage-based diets to have higher incidence of discoloration when compared to grain-fed cattle, resulting in a lower overall retail desirability rating. Concentrate-supplemented cattle showed less surface-color discoloration compared to grass fed beef following a 6 d display period, however there was no difference found between grain-supplemented cattle and clover fed cattle (Reagan et al., 1977). This increase in discoloration may be due to the increased polyunsaturated fatty acid (PUFA) content associated with forage-based diets (Garmyn et al., 2010), as the susceptibility of fatty acids to oxidization is related to their degree of unsaturation.

Proximate Analysis

Vitamins and minerals in grass-finished beef have been shown to have greater levels of Na, Zn, and, vitamin B_{12} than grass-finished strip steaks, and lower levels of Mg, P, and K, which may be due to the higher fat content found in ground beef (Leheska et al. 2008). Duckett et al. (1993) also reported an increase in Fe and K content as fat content increased. Differences in fat content were found between grain fed beef and grass-fed strip steaks (4.4% and 2.8%, respectively), which can be attributed to the increased plane of nutrition which would allow for a greater amount of marbling to be deposited in grain-fed beef (Leheska et al., 2008; Daley et al., 2010). Despite the difference in fat content, no difference was found in cholesterol content. Reagan et al. (1977) and Leheska et al. (2008) found product from cattle finished on forage or clover had higher moisture content compared to grain-supplemented cattle, likely due to the inverse relationship of water and fat. However, Melton et al. (1982c) found no difference in moisture or fat content of product from steers fed high- or low-energy diets in grass- and grain-based finishing diets, when finished to a common end point.

Fatty Acids

Studies have shown the specific species of forage, season of cutting, as well as interval of cutting may affect the fatty acid composition of grasses, potentially influencing fatty acid profile within grass-fed beef (Dewhurst et al., 2000; Dierking et al., 2010a; Clapham et al., 2005). Dierking et al. (2010b) also found the incorporation of legumes into cool-season grasses did alter the fatty acid profiles of the forages themselves, however the fatty acid composition of the pastures did not influence the composition of intramuscular fat in cattle grazing these pastures. Specifically, Dewhurst et al. (2000) found total fatty acid concentrations (g/kg DM) for cultivars of perennial ryegrass (*Lolium perenne*), annual ryegrass, and hybrid ryegrass (*L. boucheanum*) were highest early and late in the season, as well as lowest during summer months. Plant lipids contain a high level of PUFA, particularly 18:2*n*-6 and 18:3*n*-3, which can be attributed to the thylakoid membranes of chloroplasts (Dewhurst et al., 2003).

Garmyn et al. (2010) stated increasing forage intake can decrease the concentration of saturated fatty acids while increasing the ratio of PUFA to saturated fatty acids, as well as, increase the concentration of conjugated linoleic acids. Studies by French et al. (2000) found when grown at similar carcass growth rates, steers with an intake of 12 kg or greater grazed forage had a higher polyunsaturated:saturated fatty acid ratio and elevated levels of CLA in intramuscular fat from the longissimus muscle, when compared to those finished on grass silage or concentrates. Additionally, steers with high forage intake showed a decreased n-6:n-3 ratio when compared to those finished on grass silage or concentrates (Leheska et al., 2008; Noci et al., 2005). An increase of the amount of time spent grazing led to a linear decrease in n-6:n-3 PUFA ratio and a linear increase in the proportion of C18:1*trans*-11, CLA*cis*-9, *trans*-11 and CLA *trans*-10, *cis*-12. Additionally, extending the time grazing led to an increase in C18:1 *trans*-11, CLA *cis*-9, *trans*-11, and C18:3 n-3 in polar lipids (Noci et al., 2005).

Melton et al. (1982c) reported that ground-beef patties from grass-fed steers which contained approximately 20% fat were found to contain more C16:1 and C18:3, and less C20:4 lipids than ground beef from limited grain-fed steers. Additionally, ground beef samples from steers forage finished during the summer contained more C17:0 and C18:0, and less C14:0, C15:0, C16:0 and C16:1 polar lipids than winter forage-finished steers (Melton et al, 1982c). Grass-fed beef has been found to contain lower total lipid content, and greater concentrations of n-3 PUFA, vaccenic, and conjugated linoleic acids than concentrate finished cattle (Duckett and Pavan, 2007). Additionally, grass-fed beef has been shown to have n-6 to n-3 ratio of less than 4:1 (Noci et al., 2005; Duckett et al., 2013; Schmidt et al., 2013). These values fall within the desirable level of n:6 to n:3 ratios, which healthcare professionals recommend to be 4:1 or less (Simopoulos, 2008).

Leheska et al. (2008) reported differences in saturated fatty acids between treatments were primarily due to a greater concentration of stearic acid (18:0) found in grass-fed ground beef. Additional differences in SFA were associated with capric acid (10:0), pentadecanoic

(15:0) and arachidic acids (20:0), with greater concentrations found in grass-fed ground beef. There was no difference in oleic acid (9*c* 18:1) between treatments, which composed the greatest proportion of monounsaturated fatty acids.

Changes in diet can impact the fatty acid composition of beef, namely in the polyunsaturated fatty acids which can subsequently impact the color, shelf life, and sensory attributes (Scollan et al., 2006). Mandell et al. (1998) speculated differences in beef flavor and strong flavors were due to decreased concentrations of 18:3 and higher concentrations of 18:1 in grain-fed beef when compared to forage-fed beef. Melton et al. (1982c) found a positive correlation (r=0.29) between C18:1 content of neutral lipids or lipids lacking a charge, and flavor score, with higher concentrations of C18:1 being associated with more desirable flavors. Additionally, Melton et al. (1982c) found lower concentrations of C14:1, C18:0, and C18:3 in the neutral lipids and C18:0 and C18:3 in polar lipids, or triglycerides, to be associated with a more desirable flavor. These findings were similar to findings of Melton et al. (1982b), where lower concentrations of 18:0 and 18:3 in neutral and polar lipids and higher concentrations of 18:1 in neutral lipid being associated with the most desirable flavor in ground beef. Undesirable flavors in forage-fed beef have been associated with 20:3, 20:4 and 22:5 (Melton, 1983). This may be due to PUFAs being highly reactive, which yield various carbonyl compounds during cooking and when exposed to autoxidative degradation, which may influence flavor (Larick and Turner, 1989).

Schmidt et al. (2013) examined a comparison of alfalfa, bermudagrass, chicory, cowpea, and pearl millet and reported fatty acid content of the LM did not differ, nor was there a difference in the total percentage of SFA, MUFA, and PUFA between treatments. Higher amounts of conjugated linoleic acid, *cis*-9 *trans*-11 isomer, were found in steers grazing bermudagrass and pearl millet than the remaining forages. Additionally, the lowest ratios of n-6: n-3 fatty acids were found in steers grazed on chicory and pearl millet.

Conclusions

Current literature shows forage specie can impact animal performance, carcass yield and quality, as well as meat quality. However, limited research has been conducted focusing on the impact of specific specie of forage for forage finishing as well as in stocker operations. While there is a large amount of literature establishing the differences between concentrate-finished cattle and grass-finished cattle, there are few studies comparing how specific forage species can impact live animal performance, as well as meat quality attributes. Therefore, the purpose of the following experiments is to determine the effects of specific cool-season forages for use in stocker operations, as well as to determine the specific effects of warm-season annual forages on animal performance, carcass yield and quality, and meat quality attributes.

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CHAPTER 3

STOCKER CATTLE PERFORMANCE ON CEREAL RYE AND RYE-BASED COOL SEASON ANNUAL MIXTURES

[1] Ford, E. M., D. Hancock, A. M. Stelzleni, and R. L. Stewart Jr. To be submitted to *Journal of Animal Science*.

Abstract

A 3-yr grazing trial was conducted to measure the potential of rye (*Secale cereale*) and rye combined with *arrowleaf (Trifolium vesiculosum L.) and crimson clover (Trifolium incarnatum L.),* annual ryegrass (*Lolium multiflorum Lam.), or* wheat (*Triticum aestivum* L.) *for* stocker cattle production. Forage combinations included 1) Cereal rye (R) 2) Cereal rye and clover (RC), 3) Cereal rye and ryegrass (RRG) and 4) Cereal rye and wheat (RW). Sixteen 0.8 ha pastures were assigned to one of four treatments in a randomized complete block design. Paddocks were planted on or about 15 October each year and grazing began in late January or early February of each year when forage availability supported grazing. Body weights were recorded for all cattle on d 0, and every 28 d thereafter following a 16-hr fast. Cumulative change in BW was higher ($P < 0.05$) for both RC and RRG in YR 1, while cattle grazing treatments of RRG had higher cumulative change in BW in YR 2. Treatments of RC and RRG had longer ($P < 0.05$) length of grazing (based on AU-days) during YR 1 than R and RW. In YR 2, RC and RRG were able to sustain a greater ($P < 0.05$) number of AU-days than R, with RW being intermediate. No differences were found in cumulative gain (kg) per hectare. These data found cattle grazing RRG were able to produce a higher amount of BW gained in two out of three years, while RC was able to sustain a higher amount of BW gained during years of cooler temperatures and abundant precipitation, and both may be a practical application in beef stocker systems.

Keywords: cool season annual forages, beef, rye

Introduction

Beef production is an important aspect of the economy in the Southeastern United States. In Georgia alone, cattle and calf production consists of 1.02 million head, generating $445 million in revenue in 2012 (NASS, 2013). With traditional feed prices reaching record highs in recent years, as well as record prices for backgrounded calves, opportunity lies in increasing body weight of feeder calves economically on high quality forages, such as cool season annuals, prior to entering a finishing program. Previous research has evaluated combinations of small grains with other small grains or legumes to improve animal performance or extend the grazing season, but results have varied.

A comparison of calves grazing wheat, ryegrass, or combinations of cereal rye with ryegrass or wheat with ryegrass by Beck et al. (2005) found no differences in ADG and BW gain/ha. While Coffey et al. (2002) found no benefit to the combinations of rye and ryegrass in stocker calf production, findings of Beck et al. (2007c) support the incorporation of ryegrass for increasing profitability, animal performance, and BW gain/ha. The incorporation of legumes into grass pastures can improve forage digestibility in grazing animals (Sleugh et al., 2000), as well as decrease fertilization costs. Additionally, crimson clover has been shown to be high in CP during the early stages through full bloom (Ball et al., 2007; USDA, 2014f). While these data indicate combinations of cool season annual forages may effectively be used in stocker production, little research has concurrently been conducted to evaluate forage productivity throughout the season in relation to sustaining animal performance. Thus, this research was designed to compare forage productivity, evaluate how forage combinations support grazing, as well as evaluate animal performance.

Methods and Materials

Pasture Management

A 3-yr study was conducted during the winters of 2009-2010, 2010-2011, and 2011-2012 (defined as YR 1, YR 2, and YR 3, respectively) on 16 0.8-ha pastures at the University of Georgia's Central Georgia Research and Education Center located in Eatonton, GA. Each experimental unit (individual pasture) was blocked into one of four replications on the basis of similar terrain and previous performance, and one of four treatments were randomly assigned to each paddock within a block. Pastures were mowed ca October 1 of the previous fall for each year, followed by an application of glyphosate ca 7 d later. Then, all pastures were no-till planted ca October 15 in each year. Treatments included 1) cereal rye (cv. 'Wrens Abruzzi') only (R), 2) cereal rye plus annual ryegrass (*Lolium multiflorum*; cv. 'Marshall'; RRG), 3) cereal rye plus wheat (*Triticum aestivum;* cv. 'AGS 2026'; RW), and 4) cereal rye plus arrowleaf clover (*Trifolium vesiculosum*; cv. 'Apache') and crimson clover (*Trifolium incarnatum*; cv. 'Dixie'; RC). The seeding rates used were 108 kg of rye seed ha^{-1} for the R treatment; 67.2 kg of rye seed and 16.8 kg of annual ryegrass seed ha^{-1} for the RRG treatment; 67.2 kg of rye seed and 67.2 kg of wheat seed ha^{-1} for the RW treatment; and 67.2 kg of rye seed, 11.2 kg of crimson clover seed, and 5.6 kg of arrowleaf clover seed ha^{-1} for the RC treatment. All treatments received 56 kg N ha^{-1} at planting. The R, RRG, and RW treatments received another 56 kg N ha^{-1} in mid-winter before grazing began, while the RC treatment received only 28 kg N ha^{-1} at this time. Then, the RRG treatment received a third 56 kg N ha^{-1} in late winter. Each fall, all pastures were fertilized according to soil tests to meet P and K requirements.

Stocking date and removal decisions were based on forage availability estimated using a calibrated rising-plate meter (RPM). At the beginning of each stocking season and every week thereafter, 50 RPM measurements were obtained at random locations located along a transect across the pens. Rising plate meter measurements were calibrated by obtaining four yield measurements from sites where RPM measurements (separate of previously mentioned RPM measurements) were recorded. Yield measurements were obtained by hand-clipping forage within a 30.5 X 30.5-cm quadrant to a height of 2.5-cm at random locations. Hand-clippings were then sorted by species, including cereal rye, the non-cereal rye component of each treatment, and non-planted species (i.e., weeds). Hand-clipped forage samples were dried to a constant weight at 60°C in a forced-air oven. Dry-weights of hand-clippings were used to estimate available DM (kg ha^{-1}) of each forage component for each treatment. As forage growth slowed in the spring and forage availability fell below 1200 kg DM ha^{-1}, individual treatments were stopped and their contribution to the experiment was terminated.

Animal Management

Angus crossbred steers (BW 250 kg ± 24 kg) were obtained from the University of Georgia's Central Georgia Research and Education Center herd. For each year, the experiment began once forage availability reached approximately 3000 kg DM ha^{-1}. Upon initiation of the experiment, steers were stratified by BW into four strata. A strata was randomly assigned to one of the four blocks, and steers from within that strata were randomly assigned to the forage treatments in that block. Weights of both experimental and put-and-take steers were obtained following a 16-h fast of feed and water at the beginning and end of each grazing period, and at 28-d intervals. Paddocks were grazed under continuous stocking at a rate of 2 steers 0.40 ha^{-1}, with 4 steers being designated tester animals. As forage mass exceeded 2800 kg DM ha^{-1}, put-and-take steers were added to maintain grazing pressure. As forage mass fell below 1200 kg DM ha^{-1}, stocking rate was reduced beginning with put-and-take cattle. Data from put-and-take cattle was used in evaluation of stocking rate and days of grazing. Body weight gain per hectare was calculated using ADG, days of grazing, and stocking rate. While on pasture, an All Weather Beef Mineral Mix for Cattle on Pasture (Table 3.1; Vigortone 3V5 S; Provimi North America, Inc; Brookville, OH) was offered ad libitum, with Rumensin (Elanco; Greenfield, IN) incorporated into the mineral mixture at a rate of 50 to 200 mg/hd/d. All practices and procedures used in this experiment were examined and approved by the University of Georgia Animal Care and Use Committee.

Statistical Analysis

Data was analyzed as a randomized complete block design using the MIXED models procedure of SAS 9.1 (Cary Institute, Inc.; Cary, NC), with rep as random effect. Since nearly all response variables exhibited a year by treatment interaction, data was analyzed and has been presented by year. Significance was determined at $\alpha \leq 0.05$ and least squares means were separated with pairwise *t* tests (PDIFF option of SAS).

Results and Discussion

The monthly average and 30-yr average temperature from October through May of each year at the experiment site are presented in Figure 3.1. Total rainfall during the experimental period was 1483 mm, 694 mm, and 659 mm for YR 1, 2, and 3, and is presented in Figure 3.2. Despite above normal precipitation from October through January for the 2009 to 2010 season, the colder than normal December and January delayed forage growth and subsequently the start of grazing until early February. While March and April had lower than normal precipitation, May had higher than normal precipitation, allowing the grazing trial to continue through June, ending on 17 June.

Although both temperature and precipitation were lower than normal during December and January of YR 2, the normal temperatures and above normal amounts of precipitation received during October and November allowed for adequate forage growth. This resulted in the grazing trial beginning on 28 January of YR 2. Normal to below normal precipitation occurred during January through April, combined with normal temperatures during this time allowed the grazing trial to continue through this time. However as no precipitation was recorded during May of YR 2, forage growth and availability became limiting, and the grazing trial ended on 20 May.

With temperatures being lower than normal during October 2011, they were above normal for the remainder of 2011 through May 2012. Despite lower than normal amounts of precipitation during October and November, December received above normal precipitation, with January through April receiving below normal amounts of precipitation, and May receiving normal amounts of precipitation. The adequate precipitation combined with higher than normal temperatures allowed for an early start of grazing (12 January), with the grazing season extending until 23 May.

Evaluation of Hand-Sampled Forage Components

The botanical composition and performance of individual forage components for YR 1 is presented in Table 3.2, Figure 3.3, and Figure 3.4. In YR 1, there were no differences in the presence of rye within each treatment until Period 9, when the availability of rye was higher ($P < 0.05$) for R than RC, RRG and RW. In Period 3, the presence of other forages was higher in RRG than RC and RW ($P < 0.05$). In both Period 4 and Period 5, the other components of RRG and RW were found to be higher ($P < 0.05$) than RC. Within each treatment, the presence of clover within RC was higher ($P < 0.05$) during Period 8 than all other periods. As the majority of growth for arrowleaf clover occurs between April and May and the majority of crimson clover production occurring in March and April (Ball et al., 2007; USDA, 2014f), these findings are consistent with expected forage performance of clover. There was no difference in the presence of ryegrass within RRG across YR 1, indicating steers preferentially grazed the ryegrass component of the treatment, which may be due to the high palatability associated with ryegrass (Dhaliwal et al., 2009; Ball et al., 2007). The presence of wheat within RW was lower ($P < 0.05$) during Period 3 and Period 9 than during Period 8 with Periods 4, 5, and 7 being intermediate. Hand-sorted forage samples were not obtained for the duration of the trial following Period 9 for YR 1.

The botanical composition and performance of individual forage components for YR 2 is presented in Table 3.3, Figure 3.5, and Figure 3.6. In YR 2, there was no difference in the presence of rye among all treatments for the duration of the grazing season. Within each treatment, the presence of clover in RC in Period 2 was lower than Period 8 as well as similar to Periods 3 through Periods 7. The largest ($P < 0.05$) presence of clover occurring in Period 8, which can be expected based on clover growth performance for the Piedmont region. There was no difference in the presence of ryegrass within RRG across the YR 2 grazing season, indicating steers preferentially grazed the ryegrass component of the treatment, which was also seen during the YR 1 grazing season. The presence of wheat in RW was higher ($P < 0.05$) during Period 7 than Period 4, with all other sampling periods being intermediate in availability of wheat. Comparing availability of other components across each period, the RC was higher ($P < 0.05$) in Period 3 (February 8) than RRG and RW. In Period 4, the other components were higher ($P < 0.05$) in RC when compared to RW, with the availability of other forage in RG being intermediate. In Period 8, RC was higher ($P < 0.05$) in the presence of other forage than both

RRG and RW. The higher presence of other components in RC when compared to RRG and RW may be attributed to the normal temperatures and amount of precipitation received during this grazing season.

The botanical composition and performance of individual forage components for YR 3 is presented in Table 3.4, Figure 3.7, and Figure 3.8. In YR 3, there were no differences in presence of rye within each treatment until Period 7, when R was higher ($P < 0.05$) than all other treatments, followed by both RC and RW ($P < 0.05$), with RRG having the lowest ($P < 0.05$) prevalence of rye. Additionally, in Period 9, RC had a higher ($P < 0.05$) amount of rye than R, with RW and RRG being intermediate. Within each treatment, RC was highest ($P < 0.05$) during Period 7 than all other periods, as can be expected based on forage growth patterns. The presence of other components in RRG was lower ($P < 0.05$) in Period 4 compared to Period 7, 9 and 10, and was similar to Periods 1, 2, 3, and 5. In Period 9 and Period 10, other components in RRG were higher ($P < 0.05$) than all other periods, followed by Period 7. Availability of other forage within RW was higher ($P < 0.05$) in Period 7 than all other periods. Within each period, RRG was higher ($P < 0.05$) than both RC and RW for Period 1, 2, 3, 5 and 9. In Period 7, RRG and RW were higher ($P < 0.05$) than RC. Below normal precipitation and above average temperatures for YR 3 may have contributed to both the lower prevalence of other components in RC as well as the higher prevalence in RRG. Additionally, total forage availability for all years is presented in Table 3.5.

Animal Performance

Average daily gain for YR 1, YR 2 and YR 3 are displayed in Figures 3.9, 3.10, and 3.11, respectively. In YR 1, there was no difference in ADG (kg/hd/d) until May 27. At this point, RC and RRG were higher ($P < 0.05$) than R and RW, as the grazing season for both treatments ended on April 28. While there was a decrease in the ADG obtained for steers remaining on RRG and RC treatments for the duration of the grazing season, ADG between treatments was similar and both treatments were able to sustain cattle approximately 50 d longer than RW and R. In YR 2, there was similar ADG between treatments until April 7. At this time, cattle on treatments of RRG and R had higher ($P < 0.05$) ADG than treatments of RC and RW, however the forage availability of R did not allow for further grazing past this point. On April 20, cattle grazing treatments of RRG had higher ($P < 0.05$) ADG than those grazing treatments of RC, with RW being intermediate. As forage availability of RW became limiting, cattle grazing those treatments were removed from pastures on May 5, resulting in only treatments of RRG and RC remaining. On May 20, ADG of cattle on RRG was higher ($P < 0.05$) than the remaining treatment of RC. In YR 3, there was a similar ADG for cattle grazing all treatments until May 5, at which time cattle grazing on RRG had a higher ($P < 0.05$) ADG than those grazing RW, with those grazing both RC and R being intermediate. At this point in time, cattle grazing treatments of RC, R and RW were removed from pastures, as forage availability became limiting. Cattle grazing pastures of RRG maintained on treatment until May 23, at which time forage availability became limiting and the grazing season ended for RRG as well.

A comparison of cumulative ADG (Table 3.6) between treatments shows no difference in ADG during the respective grazing season for each treatment during YR 1. In YR 2, both R and RG had higher cumulative ADG than cattle grazing RW and RC during their respective grazing seasons. No differences in cumulative ADG were found between treatments during YR 3.

Cumulative change in BW for all years is displayed in Figure 3.12. In YR 1, cattle had a cumulative change in BW of 93 kg/hd, 135 kg/hd, 125 kg/hd, and 90 kg/hd for R, RC, RRG and RW, respectively. This resulted in a higher ($P < 0.05$) cumulative change in BW for RC and

RRG when compared to both R and RW. This can be attributed to the shorter length of grazing for those cattle grazing R and RW. In YR 2, cattle had a cumulative weight gain of 84 kg/hd, 94 kg/hd, 141 kg/hd, and 90 kg/hd for R, RC, RRG and RW, respectively. This resulted in cattle grazing RRG to have a higher ($P < 0.05$) cumulative change in BW than all other treatments. During YR 3, cattle had a cumulative change in BW of 116 kg/hd, 119 kg/hd, 113 kg/hd, and 115 kg/hd, with no difference found between treatments. Cumulative ADG of cattle grazing treatments of R were similar to those found by Beck et al. (2005). While this study found cattle grazing RRG to have cumulative ADG of 0.94 kg/hd, 1.27 kg/hd, and 0.87 kg/hd, Mullenix et al. (2012) found steers grazing a combination of rye and ryegrass to have an ADG of 1.13 kg/hd. Findings of Beck et al. (2005) found cattle grazing these forages to have an ADG of 1.32 kg/h over a three year period. Although the cumulative ADG found in this study was lower in two out of three years, RRG was able to support grazing as long or longer than the other treatments used in this experiment. In comparing forage systems, Beck et al. (2007c) found the incorporation of ryegrass with small grains (oats, rye, or wheat) increased grazing (d/ha; 600 d compared to 516), increased BW gain/ha (514 kg compared to 354 kg), and increased net return/ha ($210.99 compared to $67.60). These authors findings suggest interseeding ryegrass with small grains can produce higher profitability, BW gain/ha, and days of grazing, indicating ryegrass is an integral components of a grazing system. Cumulative ADG for cattle grazing pastures of RW were found to be higher than found by Beck et al. (2008), who found steers grazing rye plus wheat to have ADG of 0.84 kg/d, 0.89 kg/d, and 0.90 kg/d, but lower than 1.17 kg/d (Beck et al., 2005) for spring grazing.

Stocking rate (AU/ha) was evaluated for each year, with YR 1, YR 2, and YR 3 presented in Figures 3.13, 3.14, and 3.15, respectively. Stocking rate for the YR 1 grazing season was similar between all treatments through April 28. However, the removal of cattle from treatments of R and RW resulted in the stocking rate of both RC and RRG to be higher ($P < 0.05$) than treatments of R and RW for the duration of the grazing season. In YR 2, there were no differences between treatments through April 7. At this date, cattle grazing treatments of R were removed from treatment due to lack of available forage. This resulted in RC, RW, and RRG being able to sustain a higher ($P < 0.05$) amount of AU/ha than R. Additionally, as RW was unable to sustain grazing past May 5, this resulted in both RRG and RC being able to sustain a higher ($P < 0.05$) amount of AU/ha than RW and R. In YR 3, all treatments were able to sustain the same number of AU/ha on February 9. On February 29, however, RC was able to sustain a greater ($P < 0.05$) amount of AU/ha than RW, with both R and RRG being intermediate. On March 8, RW was able to sustain a greater ($P < 0.05$) amount of AU/ha than both RC and R, with RRG being intermediate. On March 29, RW maintained a higher ($P < 0.05$) amount of AU/ha than both RC and RRG, with R being intermediate. On April 5, treatments of RW, RC, and R maintained a higher ($P < 0.05$) amount of AU/ha than RRG, with no differences in AU/ha on April 20. At this time, treatments of R, RC, and RW were no longer able to sustain grazing, resulting in RRG sustaining a higher ($P < 0.05$) number of AU/ha than all other treatments.

Length of grazing (based on AU-days) is shown in Figure 3.16. During the grazing season of YR 1, treatments sustained 182 AU-days, 248 AU-days, 268 AU-days, and 188 AU-days for R, RC, RRG and RW, respectively. This resulted in RC and RRG accumulating a higher amount ($P < 0.05$) of AU-days than both R and RW. In YR 2, treatments were able to sustain 156 AU-days, 195 AU-days, 212 AU-days and 185 AU-days for R, RC, RRG and RW, respectively. This resulted in both RC and RRG being able to sustain a greater number of AU-days than R ($P < 0.05$), with RW being intermediate. During the YR 3 grazing season, treatments of R, RC, RRG, and RW accumulated 220, 211, 238, and 243 AU-days, respectively, with no differences found between treatment. Findings of Mullenix et al. (2012) found pastures of rye plus ryegrass able to sustain 547 grazing days, while this study evaluated AU, finding RRG able to sustain 268, 212, and 238 AU-days each year. As this study found RW to sustain 188, 185, and 243 AU-days each year, Beck et al. (2008) found this forage combination able to sustain 590 grazing days/ha, 440 grazing days/ha, and 687 grazing days/ha over a three-year study.

Cumulative gain (kg) per hectare was also evaluated for YR 1, YR 2 and YR 3, and is shown in Figure 3.17. In YR 1, cattle had a cumulative gain of 212, 279, 256, and 203 kg/ha for treatments of R, RC, RRG, and RW, respectively. In YR 2, cattle grazing R had a cumulative gain/ha of 253 kg, while RC, RRG, and RW had cumulative gains of 235, 283, and 241 kg/ha. In YR 3, cattle had cumulative gains of 222, 224, 203, and 227 kg/ha. No differences were found between treatments (P = 0.3495), and no year by treatment interaction was found (P = 0.0892).

Implications

Results from this study illustrate the potential value of forage combinations of rye plus ryegrass, as well as rye plus clover, for beef cattle production systems in the Southeastern United States. Under the growing conditions in the present study, the forage combinations of rye plus ryegrass, as well as rye plus clover, were able to maintain a higher number of animal unit days in two out of three years. Cattle grazing combinations of rye plus ryegrass were able to produce a higher amount of BW gained in two out of three years, with rye plus clover able to sustain a higher amount of BW gained during years of cooler temperatures and abundant precipitation. Additionally, the use of clover within a forage system provides the potential for decreased costs, as the ability of clovers to fix N decrease fertilization cost throughout the grazing season. As both treatments of rye and rye plus wheat showed shorter grazing systems, and were associated with lower weight gained (kg/hd) in two out of three years, these forage systems may not be advantageous to use in beef cattle stocker operations.

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Table 3.1 Composition of Vigortone 3V5 S All Weather Beef Mineral for Beef Cattle on Pasture.

Mineral	Avg
Calcium (Ca)	22.00%
Phosphorus (P)	3.5%
Salt (NaCl)	20.00%
Magnesium (Mg)	1.0%
Copper (Cu), ppm	2,000
Selenium (Se), ppm	26.40
Zinc (Zn), ppm	7,500
Vitamin A, IU per lb	400,000
Vitamin $D_{3,}$ IU per lb	20,000
Vitamin E, IU per lb	200

Figure 3.1. Actual and 30-yr average temperatures from October through June by year at the experiment site.

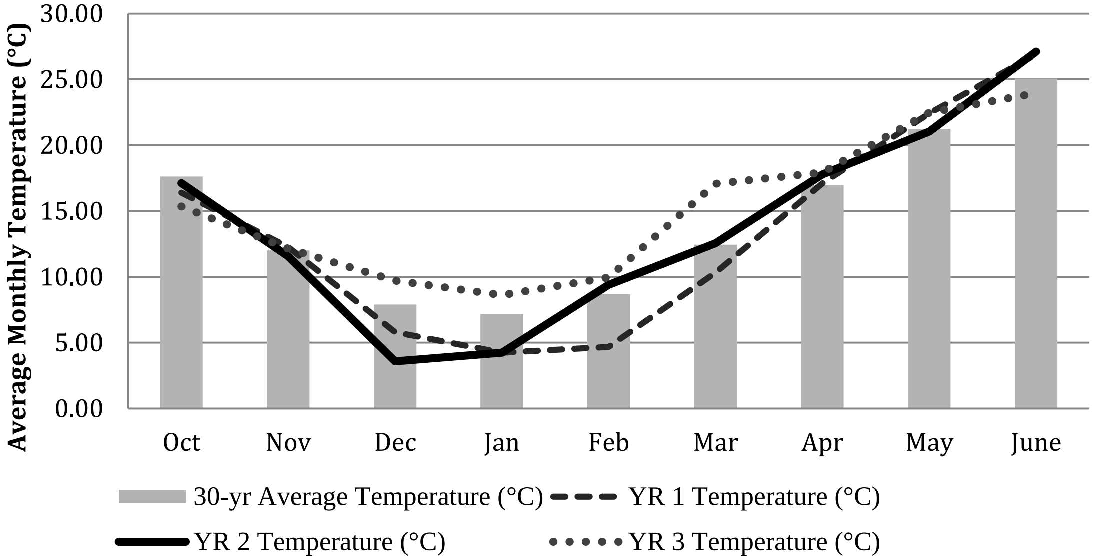


Figure 3.2. Actual and 30-yr average precipitation from October through June by year at the experiment site.

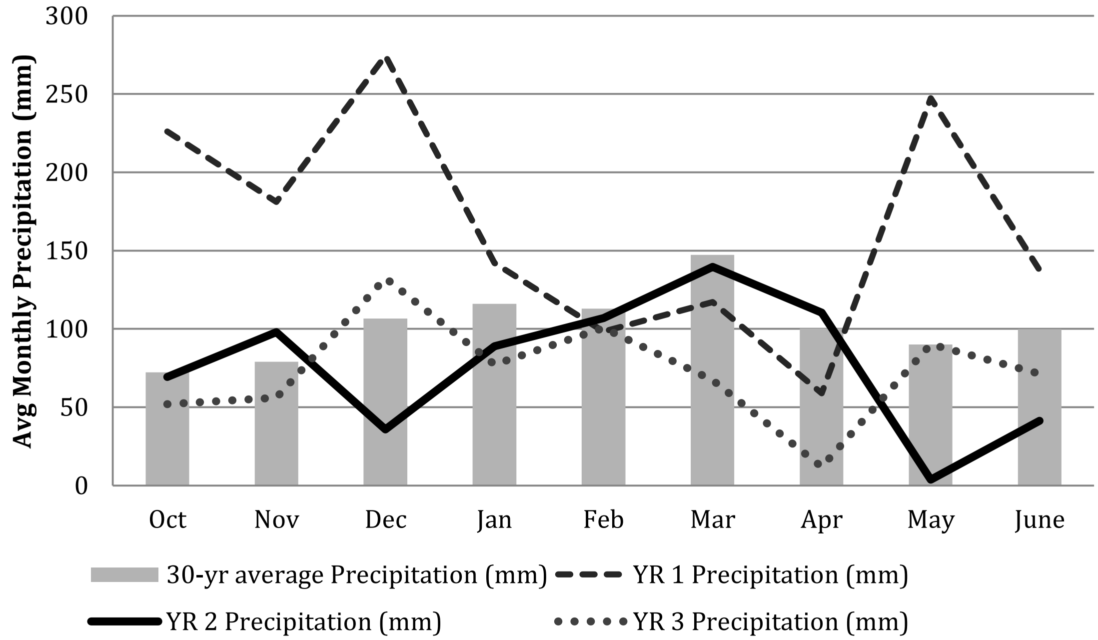


Table 3.2. Mean of clover, ryegrass, and wheat components in rye based treatments for hand separated forage samples in YR 1.*

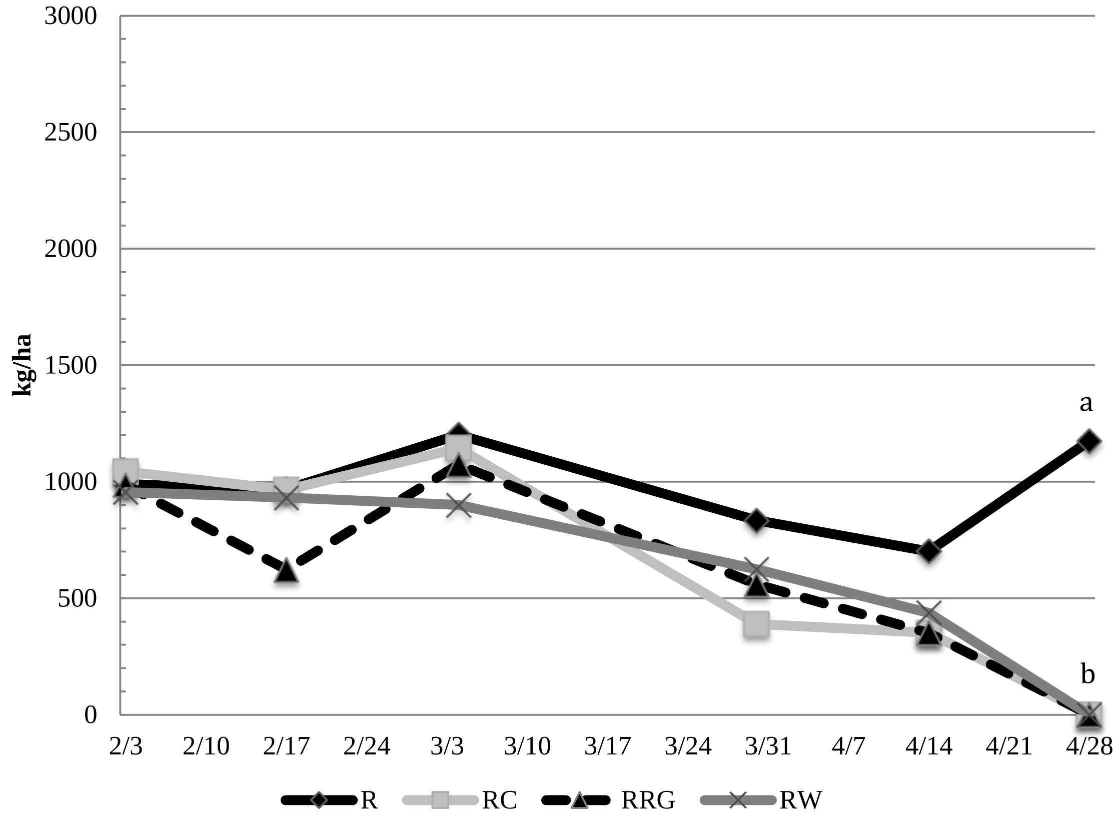
	Treatment			
	Clover	Ryegrass	Wheat	SEM
Date	----------------------	kg/ha	------------------	
2/3	0^{by}	135^{x}	51^{by}	35.3
2/17	0^{by}	112^{x}	140^{abx}	16.1
3/4	0^{by}	151^{x}	147^{abx}	49.3
3/30	34^{b}	171	148^{ab}	130.6
4/14	335^{a}	136	229^{a}	70.7
4/28	0^{b}	0	0^{b}	172.4
SEM	76.0	136.0	61.0	

*None of the treatments (to include Rye) had significant amounts of weeds or non-desired components within treatment

[ab]Least squares means within a column with different superscripts are different ($P < 0.05$).

[xy]Least squares means within a row with different superscripts are different ($P < 0.05$).

Figure 3.3. Performance of rye from hand separated forage samples in YR 1 for treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW).



[abc] Least squares means within a period with different superscripts are different (*P* < 0.05).

Figure 3.4. Botanical composition of rye, rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) for YR 1.

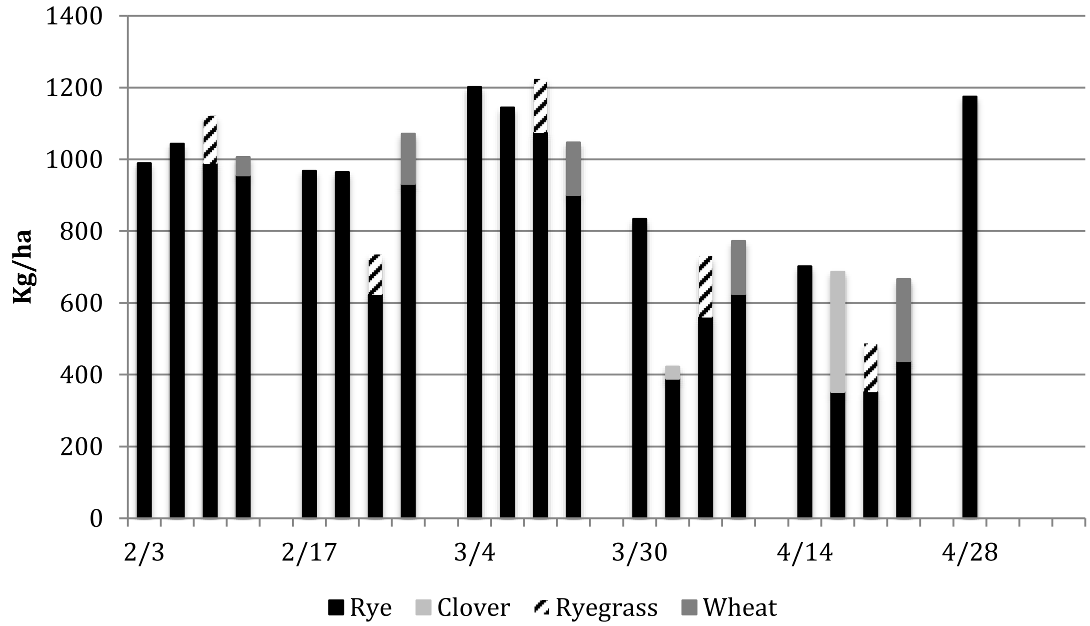


Table 3.3. Mean of clover, ryegrass, and wheat components in rye based treatments for hand separated forage samples in YR 2*.

	Treatment			
	Clover	Ryegrass	Wheat	SEM
Date	----------------------kg/ha------------------			
1/27	0^{bc}	27	60^{ab}	38.6
2/8	176^{bx}	30^{y}	87^{aby}	35.3
2/23	57^{bx}	43^{xy}	11^{by}	16.1
3/10	97^{b}	60	78^{ab}	49.3
3/23	116^{b}	141	164^{ab}	40.7
4/6	226^{b}	168	198^{a}	130.6
4/20	633^{ax}	220^{y}	143^{aby}	81.4
SEM	86.7	156.3	61.0	

*None of the treatments (to include Rye) had significant amounts of weeds or non-desired components within treatment

^{abc}Least squares means within a column with different superscripts are different ($P < 0.05$).

^{xy}Least squares means within a row with different superscripts are different ($P < 0.05$).

Figure 3.5. Forage mass of rye from hand separated forage samples in YR 2 for treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW).

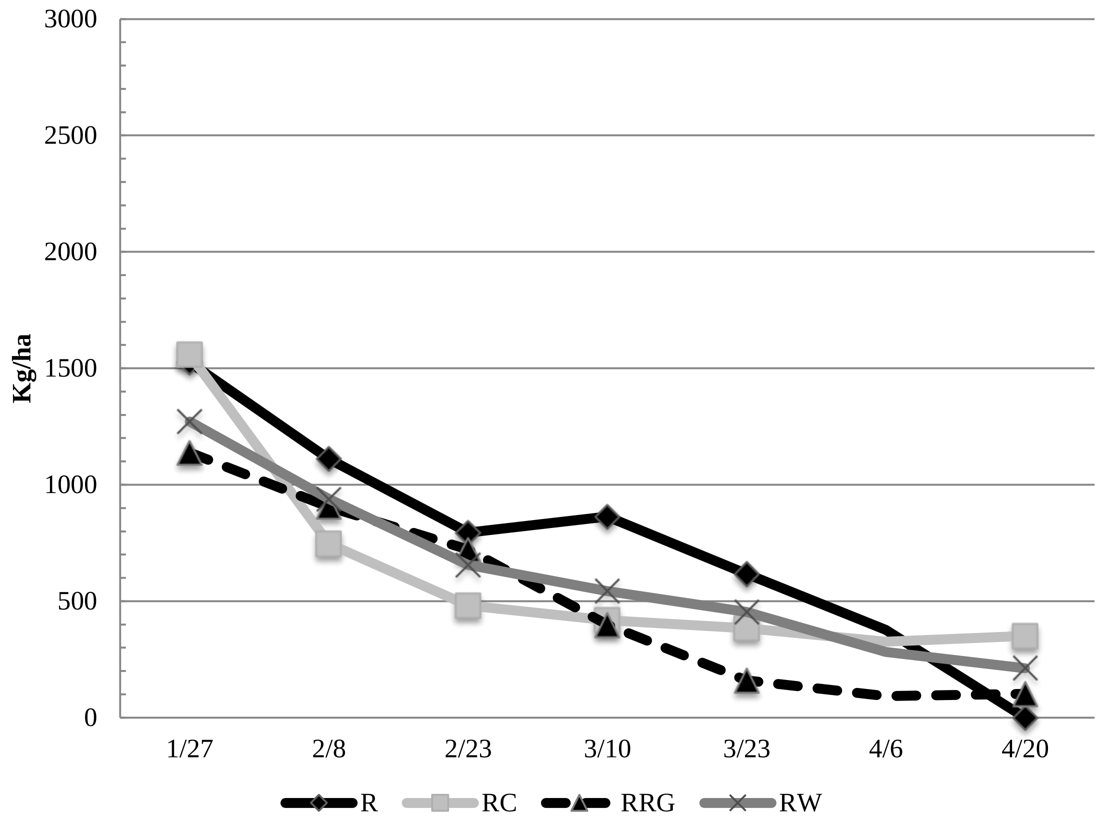


Figure 3.6. Botanical composition of rye, rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) for YR 2.

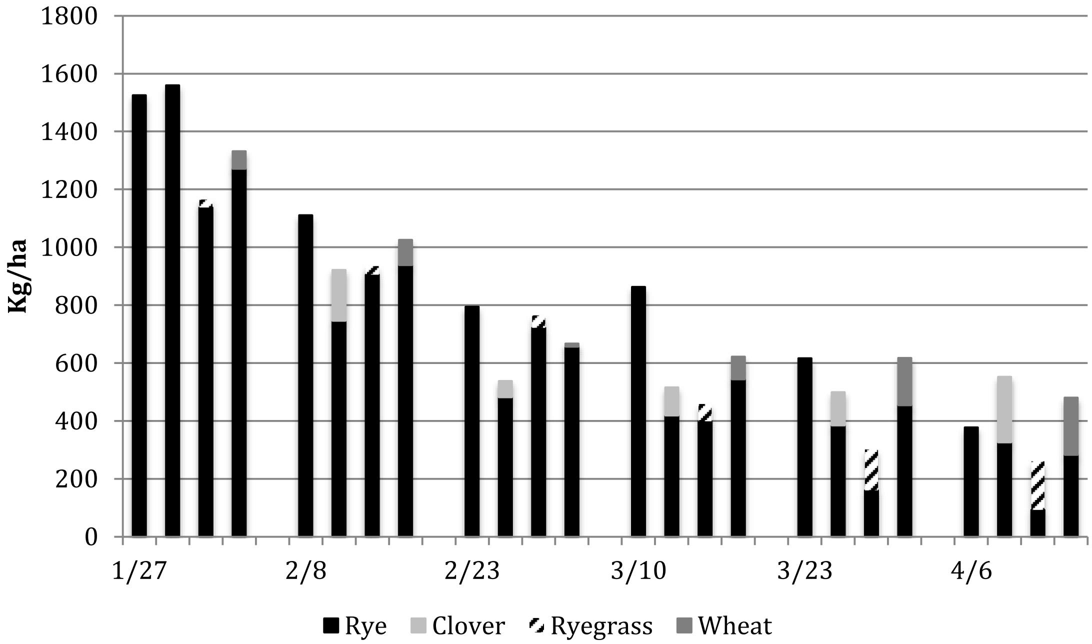


Table 3.4. Mean of clover, ryegrass, and wheat components (kg/ha) in rye based treatments for hand separated forage samples in YR 3.*

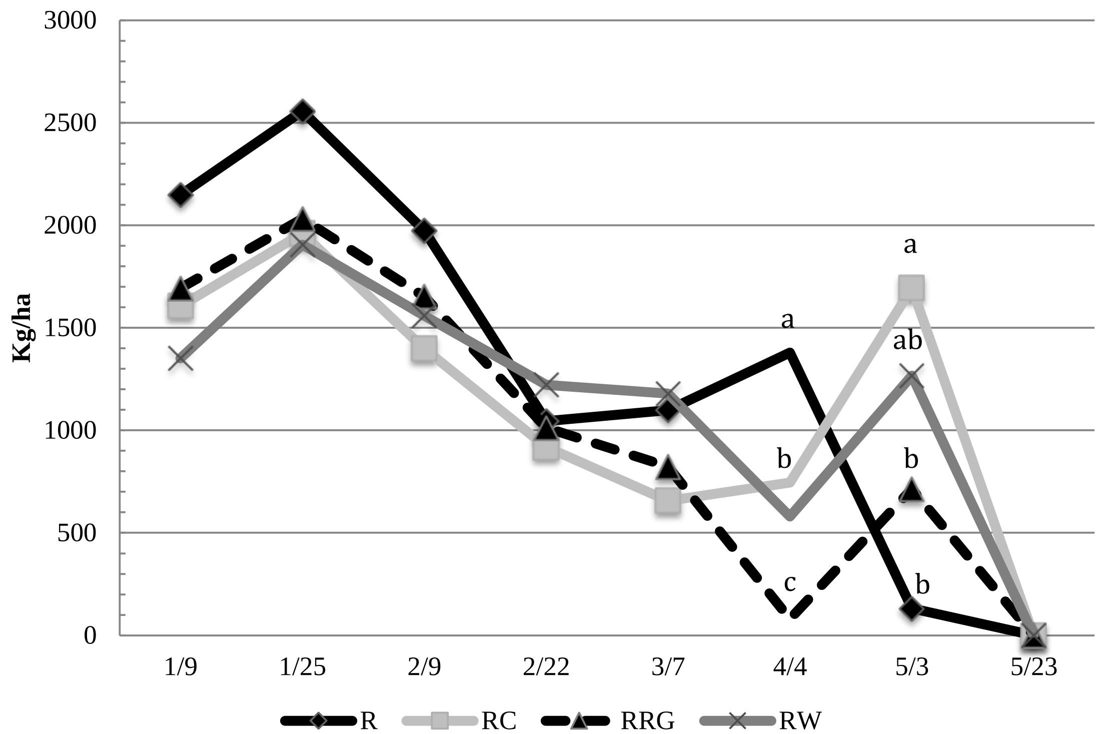
	Treatment			
	Clover	Ryegrass	Wheat	SEM
Date	--------------------kg/ha--------------------			
1/9	0^{by}	482^{cx}	121^{by}	88.9
1/25	0^{by}	230^{cx}	46^{by}	38.6
2/9	0^{by}	236^{cx}	63^{by}	35.3
2/22	0^{b}	40^{cd}	139^{b}	16.1
3/7	0^{by}	271^{cx}	59^{by}	48.2
4/4	502^{ay}	930^{bx}	887^{ax}	130.6
5/3	201^{by}	1510^{ax}	151^{by}	172.4
5/23	.	1579^{a}	.	.
SEM	76.0	136.0	61.0	

*None of the treatments (to include Rye) had significant amounts of weeds or non-desired components within treatment

^{abcd}Least squares means within a column with different superscripts are different ($P < 0.05$).

^{xy}Least squares means within a row with different superscripts are different ($P < 0.05$).

Figure 3.7. Forage mass of rye from hand separated forage samples in YR 3 for pastures of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW).



[abc]Least squares means within a period with different superscripts are different ($P < 0.05$).

Figure 3.8. Botanical composition of rye, rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) for YR 3.

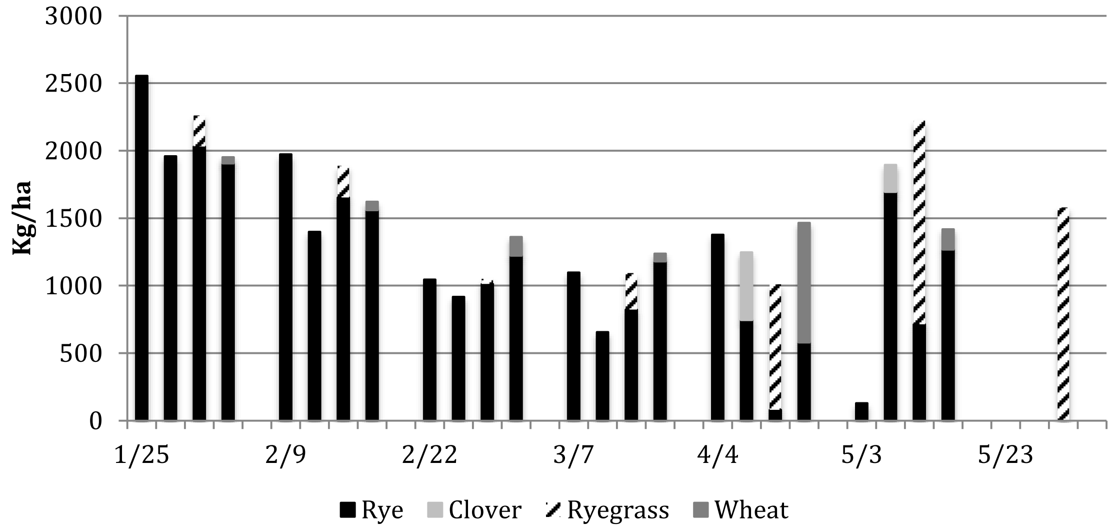
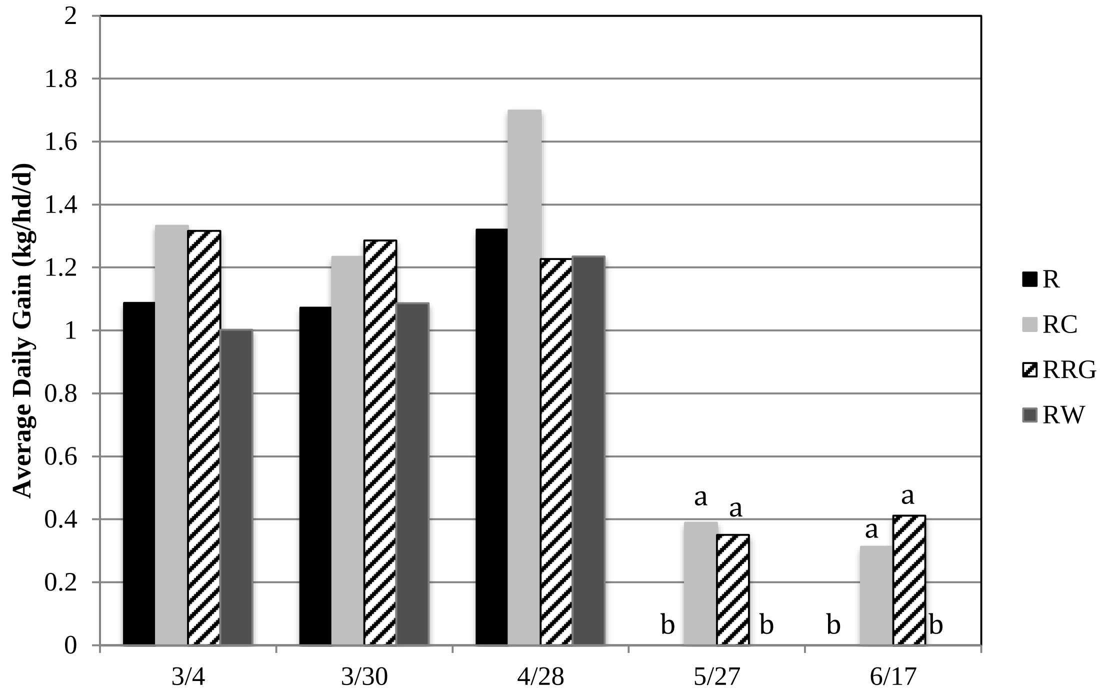


Table 3.5. Total available forage of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) for YR 1, YR 2 and YR 3.

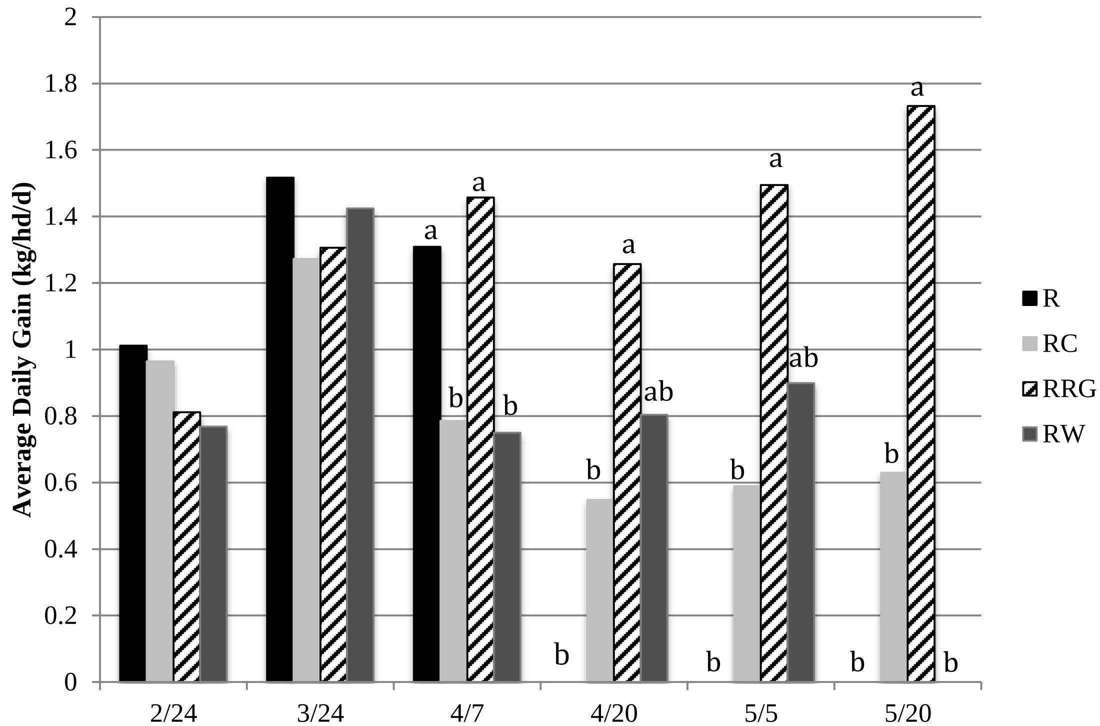
	Treatment			
Date	Rye	RC	RRG	RW
YR 1	--------------------------------kg/ha----------------------------			
2/3	989	1044	1121	1006
2/17	968	964	735	1072
3/4	1201	1144	1224	1047
3/30	833	423	731	772
4/14	702	687	487	667
4/28	1175	0	0	0
YR2	--------------------------------kg/ha----------------------------			
1/27	1526	1559	1164	1331
2/8	1111	922	935	1025
2/23	794	538	764	667
3/10	863	516	459	621
3/23	617	499	301	618
4/6	377	552	260	480
4/20	0	983	321	356
YR 3	--------------------------------kg/ha----------------------------			
1/9	2148	1606	2175	1473
1/25	2556	1961	2262	1952
2/9	1974	1399	1888	1622
2/22	1045	918	1052	1361
3/7	1099	656	1094	1237
4/4	1379	1247	1010	1466
5/3	131	1895	2223	1418
5/23	0	0	1579	0

Figure 3.9. Average daily gain for steers grazing treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 1 grazing season.



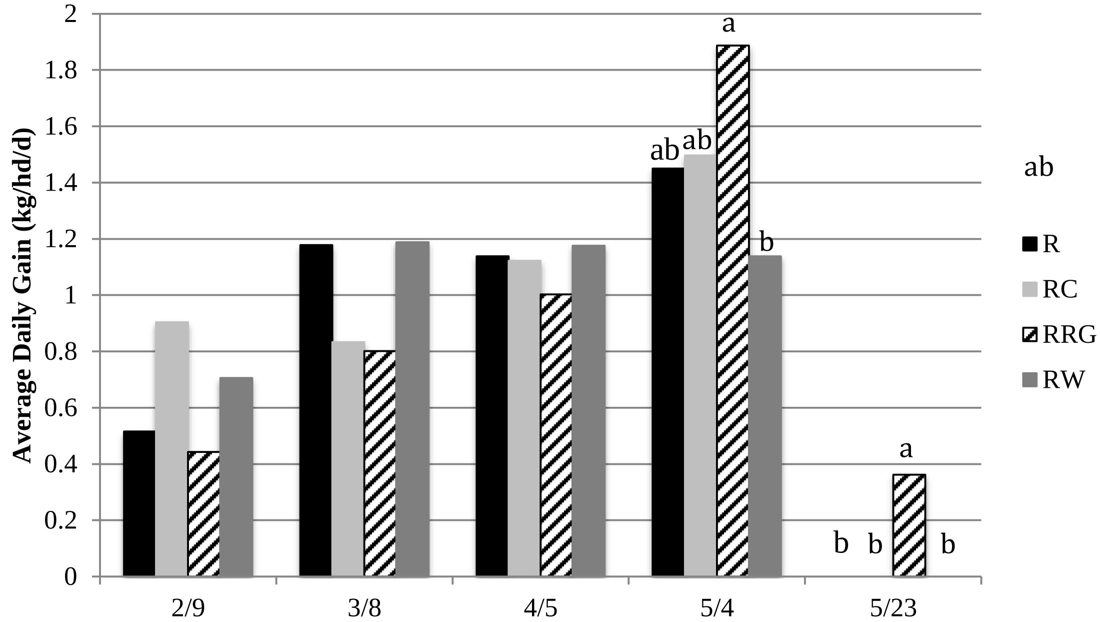
abcLeast squares means within a period with different superscripts are different (*P* < 0.05).

Figure 3.10. Average daily gain for steers grazing treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 2 grazing season.



[abc]Least squares means within a period with different superscripts are different ($P < 0.05$).

Figure 3.11. Average daily gain for steers grazing treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 3 grazing season.



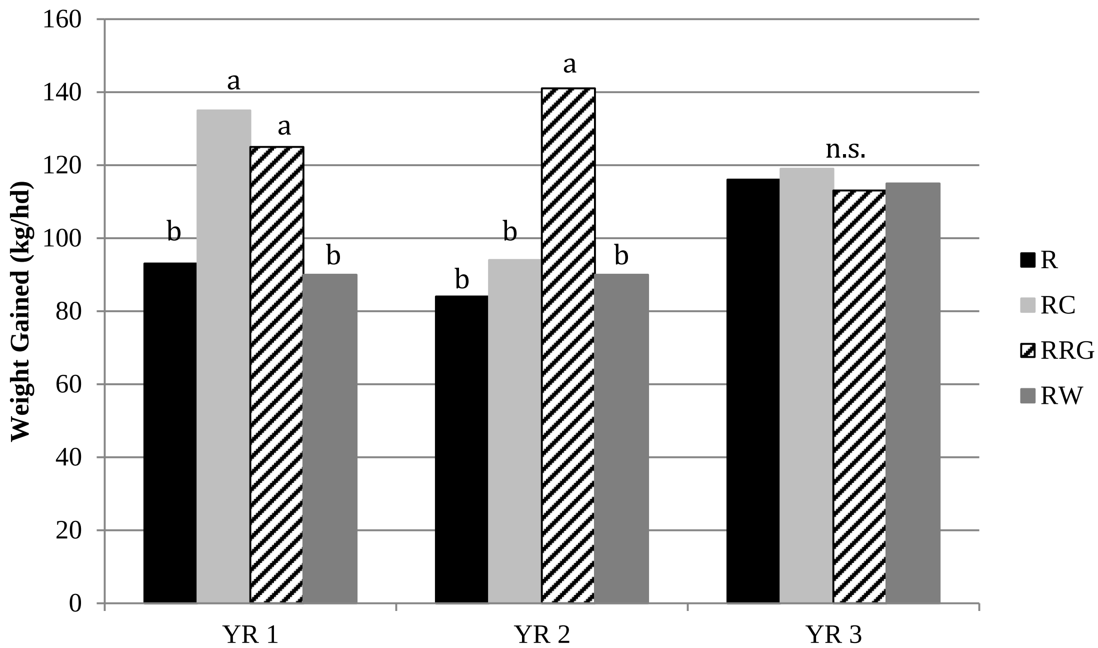
[abc]Least squares means within a period with different superscripts are different ($P < 0.05$).

Table 3.6. Least squares means for cumulative average daily gain for cattle grazing treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the respective grazing season for each treatment for YR 1, YR 2, and YR 3.

	Treatment				
	R	RC	RRG	RW	SEM
	-------------------------------kg/hd/d-----------------------------				
YR 1	1.12	1.06	0.94	1.08	0.08
YR 2	1.24[a]	1.05[b]	1.27[a]	1.03[b]	0.08
YR 3	1.04	1.06	0.87	1.02	0.07

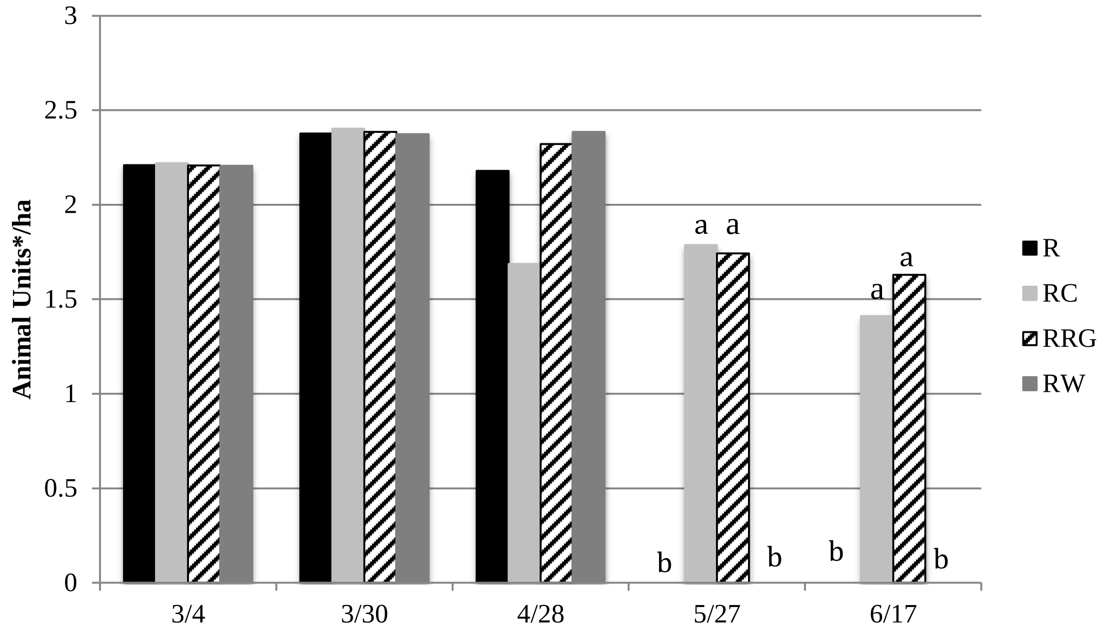
[ab]Least squares means within a row with different superscripts are different ($P < 0.05$).

Figure 3.12. Cumulative change for steers grazing treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 1, YR 2, and YR 3 grazing seasons.



[abc]Least squares means within year with different superscripts are different ($P < 0.05$).

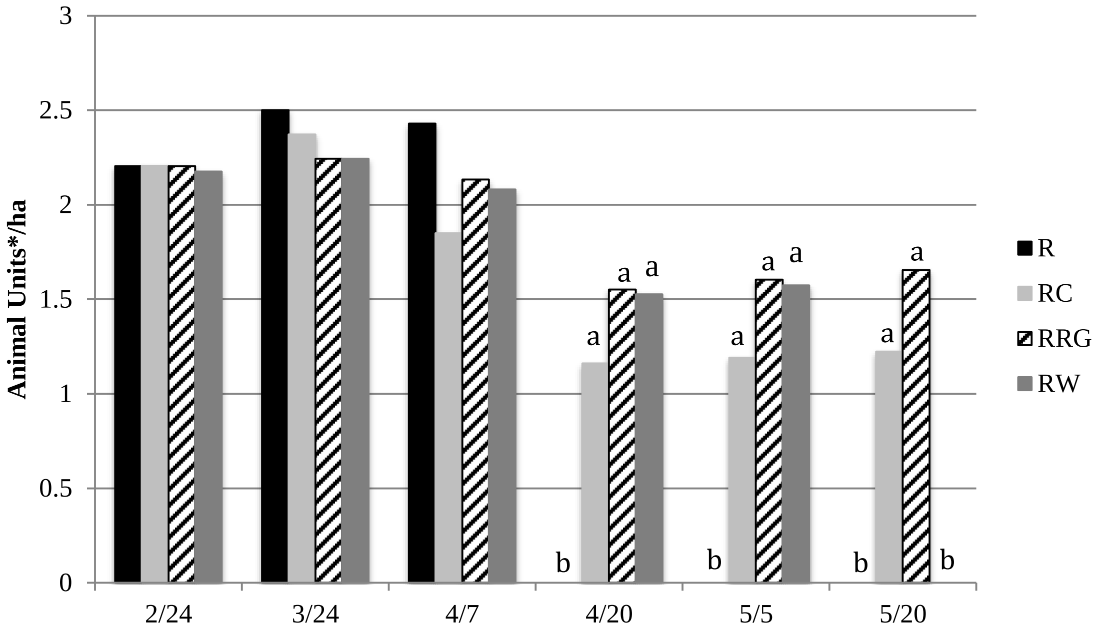
Figure 3.13. Stocking rate on treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 1 grazing season.



*Animal units defined as one mature, non-lactating bovine (middle-third of pregnancy), weighing 500 kg and fed at a maintenance level (Allen et al., 2011).

[abc]Least squares means within a period with different superscripts are different ($P < 0.05$).

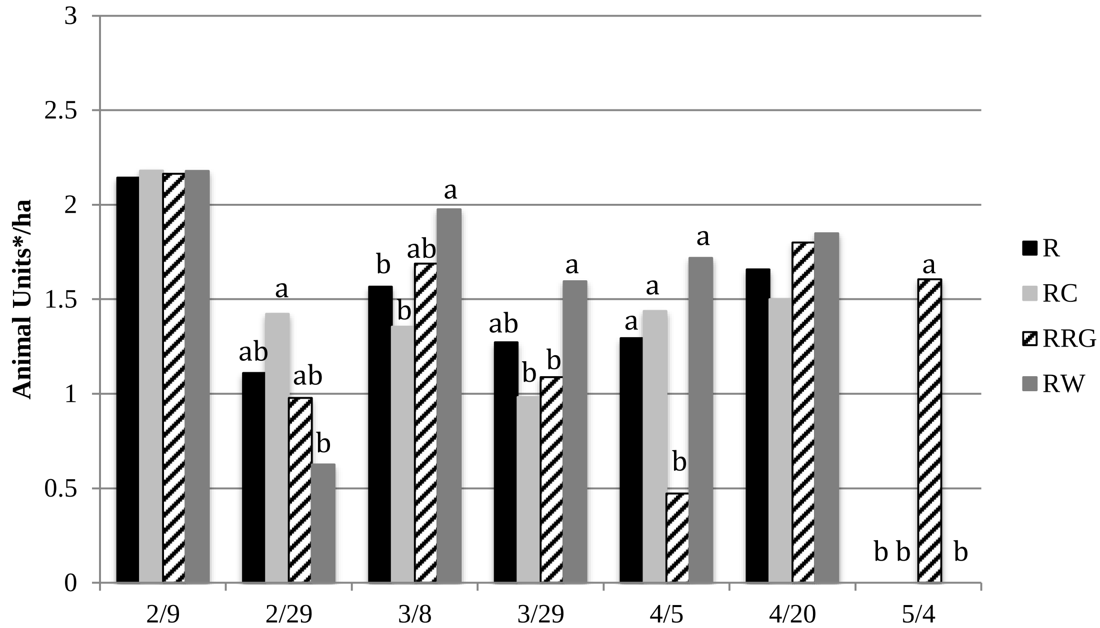
Figure 3.14. Stocking rate on treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 2 grazing season.



*Animal units defined as one mature, non-lactating bovine (middle-third of pregnancy), weighing 500 kg and fed at a maintenance level (Allen et al., 2011).

[abc]Least squares means within a period with different superscripts are different ($P < 0.05$).

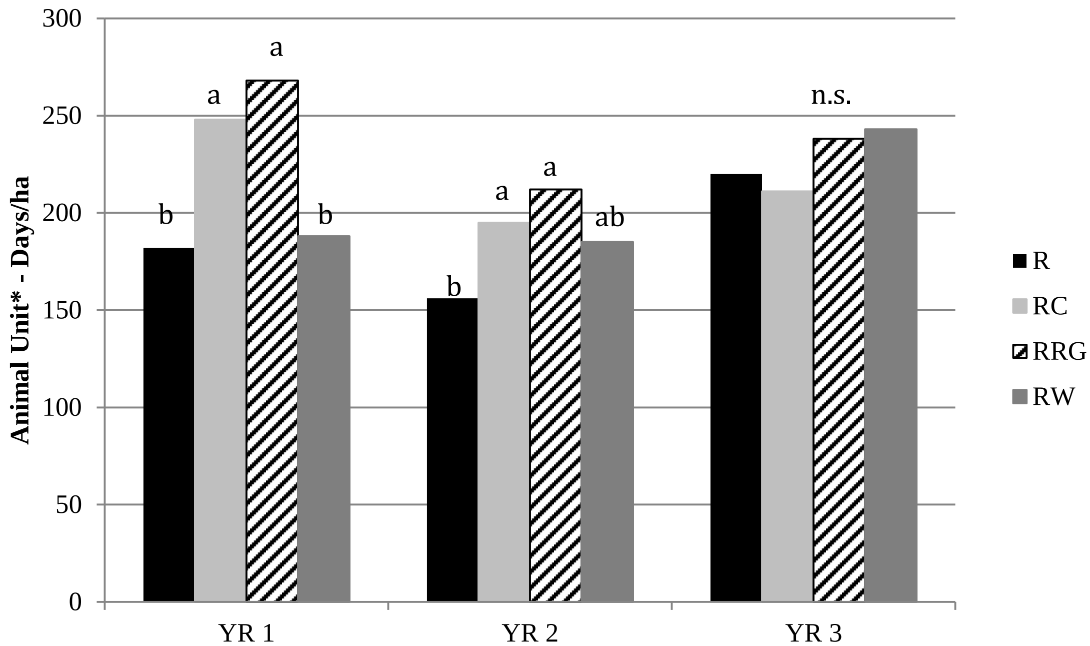
Figure 3.15. Stocking rate on treatments of rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 3 grazing season.



*Animal units defined as one mature, non-lactating bovine (middle-third of pregnancy), weighing 500 kg and fed at a maintenance level (Allen et al., 2011).

abc Least squares means within a period with different superscripts are different ($P < 0.05$).

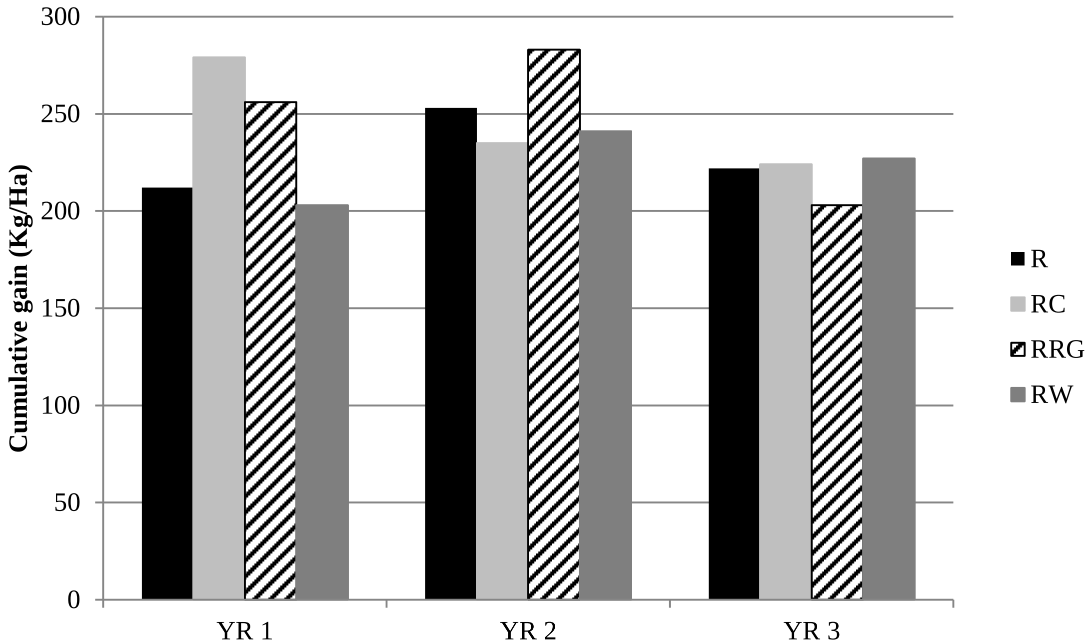
Figure 3.16. Animal unit days/ha for rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 1, YR 2, and YR 3 grazing seasons.



*Animal units defined as one mature, non-lactating bovine (middle-third of pregnancy), weighing 500 kg and fed at a maintenance level (Allen et al., 2011).

[abc]Least squares means within year with different superscripts are different ($P < 0.05$).

Figure 3.17. Cumulative gain per hectare for cattle grazing rye (R), rye plus clover (RC), rye plus ryegrass (RRG), and rye plus wheat (RW) during the YR 1, YR 2, and YR 3 grazing seasons.



[abc]Least squares means within year with different superscripts are different ($P < 0.05$).

CHAPTER 4

EFFECTS OF WARM SEASON ANNUAL FORAGE FINISHING SYSTEMS ON ANIMAL PERFORMANCE, CARCASS AND MEAT QUALITY

[1] Ford, E. M., D. Hancock, A. M. Stelzleni, and R. L. Stewart Jr. To be submitted to *Journal of Animal Science*.

Abstract

Angus-cross steers (n = 32; initial BW 353 ± 5 kg) were used in an 83-d grazing study to assess the effects of forage specie on animal performance, carcass characteristics, and meat quality. Treatments included pearl millet (PM), pearl millet plus crabgrass (PMCG), sorghum-sudangrass (SS) and brown midrib sorghum-sudangrass (BMR). Steers were stratified by weight and randomly assigned to a treatment within block. Sixteen 0.73-ha pastures were blocked by previous pasture management (established fescue, no-till drilling, conventional tillage) and served as the experimental unit (n = 4; with two steers per treatment). No differences were observed between treatments for initial BW, final BW, and cumulative ADG. Cattle grazing treatments of SS had more yellow fat color when compared to all other treatments ($P < 0.01$). Cattle grazing treatments of PMCG had the greatest ($P<0.05$) overall maturity score (A^{64}), which was attributed to the steers on PMCG having the greatest ($P<0.05$) lean maturity (B^{40}). Steers grazing treatments of BMR had a greater ($P=0.01$) content of C 14:1. No differences were found for total SFA, MUFA, PUFA, CLA, or fatty acid ratios. Shelf life data found on d 1 SS had the greatest hue value, followed by PM, which was greater than BMR and PMCG. On d 3, PM had the highest value for hue, followed by BMR, with PMCG and SS having the lowest hue. On d 7, SS and BMR had the highest hue values, with PMCG being intermediate, and PM having the lowest values. There was no treatment or treatment by day interaction for any objective color measurements, while only hue and discoloration had treatment by day interactions during shelf life evaluation. Sensory data found brown midrib (BMR) and SS had the greatest amount of off-flavor, followed by PM, with PMCG having the least amount of off-flavor. Although statistically different, all treatments were below levels of "Threshold off-flavor" and may not be biologically significant. These findings suggest these forage systems may be used in forage finishing productions with minimal impact on carcass and meat quality.

Keywords: beef; summer annual forages; meat quality; palatability

Introduction

There has been an increase in consumer and restaurateur interest in locally-produced and forage-finished products (Maynard, et al., 2003; Darby et al, 2006), a general growing interest in grass-fed or pasture-finished beef (Lacy et al., 2007), as well as a consumer willingness to pay for local and grass-finished product (Lacy et al, 2007; Darby, et al., 2006). This growing interest in grass-fed or pasture-finished beef may be attributed to perceived health benefits of forage-finished beef. While there is an abundant amount of data comparing grain finished to grass finished beef (Garmyn et al., 2010; Reagan et al., 1977; Leheska et al., 2008; Bidner et al., 1981; Duckett et al., 2007), little research has been conducted comparing the production and quality of cattle finished on different warm season annual forages. The temperate climate of the Southeast allows for the growth of forage production throughout most of the year, creating an opportunity for producers in this region to forage finish cattle on a consistent basis. However, high quality forages that persist summer conditions while supporting adequate cattle performance are necessary. While summer annual forages have the potential to satisfy these needs, there is little data comparing their impact animal performance and carcass characteristics. Therefore, the objective of this study was to examine four warm season annual forage treatments for use in summer forage finishing of beef cattle in terms of animal performance, carcass characteristics, beef quality, and shelf life of the product.

Methods and Materials

An 83-d forage-finishing grazing study was conducted through June through September 2013. The experiment was conducted at the University of Georgia J. Phil Campbell Sr. Research and Education Center in Watkinsville, GA. All practices and procedures used in this study were examined and approved by the University of Georgia Animal Care and Use Committee.

Forage Treatments

Forage treatments of pearl millet (PM; *Pennisetum glaucum,* cv. 'Tifleaf 3'), pearl millet plus crabgrass (PMCG; *Digitaria sanguinalis,* cv. 'Red River'), sorghum-sudangrass (SS; *Sorghum bicolor x S. bicolor ssp. drummondii,* cv. 'Sugargrazer'), and brown midrib sorghum-sudangrass (BMR; *Sorghum bicolor x S. bicolor ssp. drummondii*; cv. 'Honey Graze') were studied. Treatments were arranged in four replicates of a randomized complete block design. Sixteen 0.73-ha pastures were blocked by previous pasture management (established fescue, no-till drilling, conventional tillage; with pastures with no-till drilling consisting of two blocks) and served as the experimental unit (n = 4). Prior to planting, pastures were mowed and sprayed with glyphosate to kill previously established forage, and the recommended lime, P, and K adjustments were applied based on soil tests (Agricultural and Environmental Services Laboratories; Athens, GA). All pastures were established between 17 May, 2013 and 20 May, 2013. Pearl millet, BMR, and SS were planted using a no-till drill (3P605NT Great Plains, Salinas, KS) at their respective recommended seeding rates of 2.75-3.67 kg/ha. The PMCG was established by planting the pearl millet as described above, while concurrently planting crabgrass at a rate of 0.42 kg/ha into the same row. An additional planting of crabgrass was made at the same rate in PMCG pastures at the initial time of planting, in order to achieve the desired seeding rate. Crabgrass seed was mixed at a 1:3 ratio with sand for a more even distribution. Sorghum-sudangrass and BMR were mowed as needed after grazing to a height of ca. 46 cm, to control forage mass and encourage vegetative growth. Additionally, put-and-take steers were utilized on all pastures in an effort to maintain grazing pressure.

Cattle Management

Thirty-two crossbred steers (BW = 353 ± 5 kg) from the University of Georgia Central Georgia Research and Education Center beef herd (Eatonton, Ga) were used in this grazing study. Upon arrival at the experiment station, one day prior to the beginning of the experiment, steers were held overnight with access to water. Steers were weighed, stratified by weight, and two steers were randomly assigned to a pasture within block. Steers were vaccinated upon arrival with Pyramid 5 + Presponse SQ (Boehringer Ingelheim; Ridgefield, CT) and Ultrabac 7 (Zoetis; Kalamazoo, MI). Additionally, a topical application of Cydectin Pour-On (Boehringer Ingelheim; Ridgefield, CT) was applied for control of internal parasites and a Y-Tex Python Magnum Insecticide Cattle Ear Tag (Y-Tex Corporation; Cody, Wyoming) was applied for fly control immediately prior to being placed on forage treatment. All steers were provided with fresh water, shade, and mineral supplement throughout the duration of the study (Table 4.1). Individual pastures were rotationally stocked and put-and-take stocking was utilized to maintain grazing pressure optimal for individual forage species regrowth (Allen et al., 2011). Paddock forage availability was visually evaluated daily and steers were rotated to different paddocks within each pasture as forage availability became limiting. Rotational grazing was employed with the use of temporary fencing in each pasture to establish paddocks. Put-and-take steers were added or removed at this time, as forage availability warranted. The two tester steers initially assigned to treatments were maintained in assigned pastures throughout the grazing season. Two steers grazing PMCG were removed from experiment due to temperament.

During the grazing period, animal ultrasound measurements were collected every 28-d. Ultrasound measurements for ribeye area (uREA), 12th rib fat thickness (uFT), rump fat thickness (uRFT), and intramuscular fat percentage (uIMF) were collected using an Aloka 500V ultrasound system which was equipped with a 17 cm-3.5 MHz transducer with wave guide (Aloka Inc. Tokyo, Japan). Images were collected on the steer's left side, with locations of imaging clipped free of hair and cleaned with a curry comb, with vegetable oil applied liberally as a sound wave copulant. Ultrasound images were captured and analyzed using Beef Imaging Analysis Feedlot software (Designer Genes Technologies, Inc., Harrison, AK). Images for uREA and uFT were collected between the 12^{th} and 13^{th} rib juncture, perpendicular to the spinal column. Images for uRFT were collected between the hooks and pins, perpendicular to the shaft of the ileum, with the termination point of the biceps femoris in the rump as a reference point. Steer weights were collected on 0d and 83 d (WW Paul Scales; IQ Plus 390-DC Monitor, Duncan, OK), and were used in analysis of Initial BW, Final BW, and ADG.

Forage Management and Composition

Available forage mass was estimated every 14-d by clipping forage within three – 0.42 m^2 areas to a height of 2.54 cm using hand-clippers, while hand grabbed samples taken in a way that simulated the selectivity of the grazing animals were also obtained to determine forage nutritive value. All forage samples were dried at 95°C to a constant weight and weights were recorded. Nutritive value samples were initially ground to 2-mm particle size (Thomas-Wiley Laboratory Mill, Model 4; Arthur H. Thomas Co., Philadelphia, PA), and subsequently ground to 1-mm particle size (Foss Cyclotec 1093; China). Samples were analyzed at the University of Georgia Feed and Environmental Water Laboratory (Athens, GA) using Near Infrared Spectroscopy (NIRS) (Foss, NIRSystems; Model 6500; Software WinISI-II, v 1.50).

Carcass Characteristics

When forage availability became limiting, steers were transported 352 km to White Oak Pastures (Bluffton, Georgia). Upon arrival, cattle were held in outside pens for a lairage time of approximately 16 h with free access to water. Following lairage, cattle were harvested under USDA federal inspection, carcasses were split, and a 4.5% lactic acid wash was applied. Immediately following harvest, HCW was measured and carcasses were chilled for 24 h at -2°C. At 24 h postmortem, the left side of the carcasses were ribbed at the 12th to 13th rib junction and allowed to bloom for 30 min. After blooming, carcass yield and quality characteristics were collected, including rib eye area (REA; cm^2), percent kidney, pelvic, and heart fat (KPH), 12th rib fat thickness over the ribeye (FT), marbling score, lean and skeletal maturity scores, subjective fat and lean color, and muscle firmness and texture. Additionally, objective color measurements of lean color were taken on the exposed surface of the ribeye at the 12th and 13th rib juncture and fat color measurements were obtained near the posterior rib. Objective CIE color measurements were obtained using a Minolta Chroma Meter (CR-310; Konica Minolta Sensing Americas, Inc.; Ramsey, NJ) with a luminant D65, 2° viewing angle, and a 50-mm diameter measuring area. Prior to use the Minolta was calibrated against a white standard tile. Measurements of L* a * b* were obtained, where L* measuring lightness, with 0 = black and 100 = white; a * measuring the red to green spectrum, with a larger number indicating more red color; and b* measuring yellow to blue spectrum, with a larger number indicating a more yellow color. Additionally, dressing percent (DP), yield grade (YG), and overall maturity were calculated.

Following data collection, boneless short loins (*longissimus lumborum)* were removed from the left side of the carcass and vacuum packaged. Vacuum packaged short loins were layered in ice and transported via cooler back to the University of Georgia Meat Science Technology Center (Athens, Georgia; 352 km), where they were held (0 ± 2°C) for 17 d of aging. Following 17 d aging, short loins were removed from vacuum packaging for fabrication into steaks 2.54-cm thick. The first three steaks cut from the anterior end were designated for use in proximate analysis and fatty acid analysis, sensory analysis, and shear force, and were vacuum packaged and frozen (-20 ± 2°C) until further analysis. The remaining steaks were retained for use in shelf life analysis, and were randomly assigned to 0, 1, 3, 5, or 7 d of simulated retail display.

Proximate Analysis

The anterior most steak was thawed for use in proximate analysis to determine composition of protein, moisture and fat, as well as FAME (fatty acid methyl ester) analysis for fatty acid determination. Steaks were thawed for 24 h at 2 ± 2°C. All external fat and connective tissue was removed. Steaks were diced, frozen in liquid N, and homogenized using a commercial blender (Waring Product Division; New Hartford, CT). Crude protein was determined by weighing 0.2 mg homogenized, dried samples in aluminum foil cups (LECO Corp., St. Joseph, MI). Cups were placed in a LECO auto-sampler and analyzed for N content using a nitrogen auto-analyzer (LECO FP-528 Nitrogen Analyzer, LECO Corp., St. Joseph, MI) and expressed as a percent of DM.

Percent moisture was analyzed according to AOAC methods (1990). Disposable aluminum pans (Fisher Scientific, Pittsburgh, PA) were dried overnight at 90°C in a forced-air oven (1350 FM VWR Oven, Sheldon Manufacturing Inc.; Cornelius, OR), then placed in a desiccator for 10 min to cool and equilibrate. Pan weight was then recorded, and one-gram (± 0.1 g) samples of homogenized meat were weighed, in duplicate, and placed in the pans. Samples were dried at 90°C for 48 h then cooled in a desiccator and weighed. Percent moisture was calculated as: *% moisture =(1- (dry wt/wet wt)) x 100.*

Percent lipid was determined based on the procedure of Folch et al. (1957). Powder homogenized samples of 1 ± 0.1 g per sample were weighed in duplicate and placed in 20 mL screw-cap glass extraction tubes. Eight and one half milliliters of methanol:water (3.5:1) was added to each sample and vortexed for 15 s, followed by the addition of 3.25 mL of chloroform, which was vortexed for 20 s. Samples were then placed on a wrist-action shaker (Burrell Wrist Action Shaker, Model 75; Burrell Corp., Pittsburgh, PA) for 1 h. Chloroform and aqueous KCl (0.37%) were added to each sample at an amount of 3.8 mL each and were inverted three times. Samples were then centrifuged for 20 min at 2250 x *g* (IEC HN SII Centrifuge, International Equipment Co; Ramsey, MN). Following centrifuging, the upper aqueous layer was aspirated and 5 mL of KCl (0.37%) was added. Tubes were inverted three more times and centrifuging and aspiration processes were repeated. Samples were then filtered into a second, clean extraction tube through a Buchner funnel with Whatman #1 (4.25 cm) filter paper using a suction flask. Filter paper was pre-wet with 2 mL of chloroform, and two-2 mL increments of chloroform were used to rinse each glass sample tube. Following filtration, samples were evaporated under N (N-EVAP Nitrogen Evaporation Systems, Organomation Associates, Inc.; Berlin, MA) to a volume of approximately 7 mL. Any portion of remaining aqueous layer was aspirated using a Pasteur pipette. The sample was transferred to a 10 mL volumetric flask and brought to volume using chloroform. Samples were transferred to 25 mL amber vials and labeled for future use in determination of fatty acids. Following transfer to brown vials, samples were hand vortexed and 2 mL of lipid extract was transferred to pre-dried, pre-weighed, and labeled 12x75 mm culture tubes. Samples were evaporated in culture tubes under N and tubes were dried for 30 min in a forced air oven at 60°C. Following drying, samples were allowed to cool in a desiccator for 10 min and weighed. Percent lipid was determined using the following equation: *% lipid = [(((tube + lipid wt)/tube wt) x 5)/wet tissue wt] x 100.*

Analysis of fatty acids was conducted using FAME (fatty acid methyl ester) analysis, through transmethylation using the remaining previously obtained lipid extract. Two milligrams of total lipids, based on a calculated percentage of lipid (on a wet tissue basis) were analyzed using an Agilent 6850 gas chromatograph (Agilent Technologies; Santa Clara, CA) equipped with an Agilent 6850 automatic sampler (Agilent Technologies; Santa Clara, CA). Individual fatty acids were identified by comparing retention times with known reference standards. Fatty acids were quantified through the incorporation of an internal standard, C 28:0 methyl ester (methyl heptacosanoate), during methylation. Fatty acids are expressed as a percent of total fatty acids (Duckett et al., 2002).

Sensory Evaluation

Steaks designated for sensory analysis were thawed (2 ± 1°C) overnight for 16-24 h, to an internal temperature of 2-5°C prior to cooking. Samples were cooked to an internal temperature of 70°C on preheated clamshell grills (George Foreman, Salton Inc., China) according to AMSA (1995). The internal temperature of samples were monitored using a Digi-Sense 12- Channel Scanning thermometer with copper-constantan thermocouples inserted into the geometric center of the steak. Following cooking, steaks were cut into 1.27 x 1.27-cm x steak thickness cubes. Six randomly selected samples were evaluated per session and two cubes per sample were placed in jars in heated yogurt makers (Euro Cuisine, Inc., Los Angeles, CA) to keep the samples warm. Once loaded, the yogurt makers were passed through a breadbasket door from the sensory kitchen to the sensory evaluation room. The sensory evaluation room was equipped with positive pressure ventilation, 8 individual booths, and red lighting to mask panelist to panelist and degree of doneness influences. A trained sensory panel of eight panelists (AMSA, 1995) evaluated samples for overall tenderness (8 = Extremely tender, 7 = Very tender, 6 = Moderately tender, 5 = Slightly tender, 4 = Slightly tough, 3 = Moderately tough, 2 = Very tough, 1 = Extremely tough), overall juiciness (8 = Extremely juicy, 7 = Very juicy, 6 = Moderately juicy, 5 = Slightly juicy, 4 = Slightly dry, 3 = Moderately dry, 2 = Very dry, 1 = Extremely dry), beef flavor intensity (8 = Extremely intense, 7 = Very intense, 6 = Moderately intense, 5 = Slightly intense, 4 = Slightly bland, 3 = Moderately bland, 2 = Very bland, 1 = Extremely bland), and off-flavor (6 = Extreme off-flavor, 5 = Very strong off-flavor, 4 = Moderate off-flavor, 3 = Slight off-flavor, 2 = Threshold off-flavor, 1 = None detected).

Slice Shear Force

For slice shear analysis, designated samples were thawed and cooked as previously described for sensory analysis. Immediately following cooking, a 1-cm-thick, 5-cm-long slice, parallel to the muscle fiber orientation, was removed for use in analysis according to USDA slice-shear force protocol (Shackleford et al., 1997). The removed slice from each sample was placed in the Instron 3365 (Instron Universal Testing Machine, Dual Column Model 3365; Instron Corp. Worldwide Headquarters; Norwood, MA) machine to allow the blade to slice perpendicular to the muscle fibers. The Instron was equipped with a 1.016 mm slice blade, which cut at a speed of 500mm/min and was equipped with a 51 kg load cell.

Shelf life

Steaks for shelf life analysis were placed on absorbent pads (Dri-Loc AC-40, Cryovac Sealed Air Company) then placed in Styrofoam trays. Styrofoam trays were wrapped with an O_2 permeable polyvinylchloride (PVC) overwrap (O_2 transmission = 23,250 mL/m^2/24 h, 72 gauge; Pro Pack Group, Oakland, NJ, USA). Packaged steaks were then placed in open coffin style display cases (Hussman; Bridgeton, MO) at the University of Georgia Meat Science Technology Center (Athens, Georgia). Steaks were held under 24 h continuous warm-white fluorescent lighting maintained at luminescence between 1610-2000 lux to simulate conditions of retail display (AMSA, 2012), and rotated daily within the case. Temperature (4 ± 2°C) within the coffin case was monitored and recorded using digital temperature loggers (TR-50U2, T & D Corp., Japan).

Objective color was measured on d 0, 1, 3, 5, and 7 using a Hunter-Lab MiniScan XE Spectrocolorimeter (Hunter Associates Laboratory; Reston, West Virginia, USA) using illuminant A 10° viewing angle. Prior to each use, the colorimeter was standardized using a black and white tile, and a saturated red tile, was utilized as a reference standard. Measurements were recorded for L*, a* and b*. Three objective color measurements were taken for each steak each day of analysis, and the average was recorded. All color measurements were taken on d 7 steaks. Calculations for hue angle $[\tan^{-1}(b^*/a^*)]$, which is a measure of redness, and chroma value $(a^{*2} + b^{*2})^{0.5}$, a measure of color vividness, were calculated. Additionally, total color difference was calculated $\Delta E = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{0.5}$ (AMSA, 2012).

Subjective color was evaluated using a five member trained panel (AMSA, 2012). Panelists were initially screened for their ability to determine differences in color by scoring ≤ 40 on the Farnsworth-Munsell 100 – Hue Test (Xrite, Grandville, MI). Panelists evaluated color on d 0, 1, 3, 5, and 7 for overall color (8 = Extremely dark red, 7 = Dark red, 6 = Moderately dark red, 5 = Slightly dark cherry-red, 4 = Slightly bright=cherry red, 3 = Moderately bright cherry-red, 2 = Bright-cherry red, 1 = Extremely bright cherry red), discoloration (8 = No discoloration, 7 = 0-5% discoloration, 6 = 5-10% discoloration, 5 = 10-25% discoloration, 4 = 25-50% discoloration, 3 = 50-75% discoloration, 2 = 75-90% discoloration, 1 = 90-100% discoloration), and worst-point color (8 = Extremely dark red, 7 = Dark red, 6 = Moderately dark red, 5 = Slightly dark cherry-red, 4 = Slightly bright=cherry red, 3 = Moderately bright cherry-red, 2 =

Bright-cherry red, 1 = Extremely bright cherry red), with worst point color being a single or combined area of at least 2 cm^2. Japanese Beef Lean Color Standards (The Japan Ham & Sausage Cooperative Association; Tokyo, Japan) were used to assist panelists in color evaluation. Similar to objective color, panelists recorded color for all days on d 7 steaks. After each day of shelf life, the respective steaks were frozen for future use in lipid oxidation analysis.

Lipid Oxidation

Thiobarbituric acid reactive substance (TBARS) analysis was adopted and modified from Ahn et al. (1998) to determine lipid oxidation. Vacuum packaged samples previously frozen from shelf life were thawed overnight at 2 ± 2°C. A 5 g sample representative of the overall steak was diced and placed in a 50 mL centrifuge tube with 15 mL deionized water. The sample was homogenized for 30 s (Ultra-Turrax IKA T18 Basic Disperser, Germany), and centrifuged at 3077 x *g* (CR 312, Jouan Inc., Winchester, VA, USA) for 10 min. One milliliter of supernatant was transferred to a disposable glass test tube (13 x 100 mL). Fifty milliliters of butylated hydroxytolulene and 2 mL of thiobarbituric acid/trichloroacetic acid was added to the mixture, then vortexed. Samples were then incubated in a hot water bath at 90°C for 15 min, followed by a cool water bath for 10 min. Test tubes were then centrifuged at 3077 x *g* (CR 312, Jouan Inc., Winchester, VA, USA) for 15 min. The supernatant was separated for spectrophotometric analysis and measured at 531 nm (Jasco V630 equipped with Spectra-manager software, Jasco Inc., Easton, MA) and fitted against a standard curve. Lipid oxidation values are expressed as milligrams of malonaldehyde (MDA) per kg of meat.

Statistical Analysis

Data was analyzed as a randomized complete block design using the MIXED procedure of SAS V 9.1 (SAS Institute Inc.; Cary, NC). Treatments were blocked by previous pasture management (established fescue, no-till drilling, conventional tillage), with the pasture serving as the experimental unit and steer serving as the observational unit. Individual steer and pasture within treatment was included as random variable. Main effects and all treatment by day interactions were analyzed when applicable. When applicable, data exhibiting a treatment by day interaction was reanalyzed by day. Significance was determined at $\alpha \leq 0.05$ and least squares means were separated with pairwise *t* tests (PDIFF option of SAS).

Results and Discussion

Precipitation during this study (May 2013 through September 2013) at the J. Phil Campbell Research and Education Center (Watkinsville, GA) was higher than the normal 30-yr mean. Precipitation in June and July was 290 and 273 mm compared to the 30-yr average of 105 and 124 mm, respectively (Figure 4.1). Temperature during this period remained approximately normal (Figure 4.2).

Forage Analysis

Chemical composition and dry matter yields are presented in Table 4.2. Crude protein and ADF concentration was similar across treatments at each harvest date ($P > 0.62$). In Week 2, NDF concentration was greatest for PM compared to PMCG ($P = 0.04$) and SS ($P < 0.01$), while BMR was similar to PM ($P = 0.14$). In Week 4, NDF values were greatest in PMCG ($P < 0.001$), which were similar to PM ($P = 0.37$). Values for BMR were lower than PMCG and PM ($P = 0.006$), however BMR was similar ($P = 0.92$) to SS in Week 4. In Week 10, NDF was greatest in SS ($P < 0.01$), which was similar to PMCG ($P = 0.72$) and BMR ($P = 0.71$), with PM containing the least ($P = 0.04$) amount of NDF. In wk 2, TDN was greatest for PMCG, which was similar to BMR ($P = 0.53$) and SS ($P = 0.54$), with TDN values for PM ($P = 0.02$) lower than PMCG. However, TDN values for both BMR ($P = 0.09$) and SS ($P = 0.62$) were similar to

PMCG. In Week 4, TDN values for BMR were similar to SS (*P* = 0.21) and PM (*P* = 0.08), but were greater than TDN values for PMCG (*P* < 0.01). However, TDN values for both SS (*P* = 0.62) and PM (*P* = 0.15) were similar to PMCG. Treatments of BMR again had a greater TDN than SS (*P* = 0.04) in Week 6, with PMCG and PM being similar to both BMR and SS in TDN value. In Week 10, TDN values for PM were similar to PMCG (*P* = 0.20), but were higher than SS and BMR (*P* < 0.01). However, TDN values for PMCG were similar to SS (*P* = 0.48) and BMR (*P* = 0.13).

Relative forage quality for Week 0 was greatest for BMR, which was similar to PMCG (*P = 0.31)*. Relative forage quality values for PMCG were similar to both SS and PM (*P* > 0.05). In Week 2, BMR had the greatest RFQ value, which was similar to PMCG and SS (*P* > 0.36), and greater than PM (*P* = 0.04). However, RFQ values for SS and PMCG were similar (*P* > 0.06) to PM. In Week 4, RFQ for BMR was greater than all other treatments (*P* = 0.04), with the remaining treatments being similar to each other (*P* < 0.11). In Week 6, RFQ values were greatest for BMR, which were similar to PMCG and PM (*P* > 0.07), and greater than SS (*P* = 0.03). Relative forage quality values for both PMCG and PM were similar to SS (*P* > 0.44). Samples of PM had the greatest RFQ value during Week 10, which were similar to PMCG (*P* = 0.24), yet were higher than both SS and BMR (*P* > 0.02). Values for PMCG were similar to both SS and BMR (*P* > 0.26). During this study, RFQ values for all treatments remained over 100 for the majority of the time. Additionally, RFQ of BMR was greatest in four out of six week samples. This may be attributed to the higher amounts of TDN and estimated TDN that were found in samples of BMR. Forage availability (kg of DM/ha; Table 4.2) exhibited a week effect (*P* < 0.01), however neither a treatment or treatment by week effect was present (*P* > 0.15).

Steer Performance

No differences were observed for initial BW, final BW, and cumulative ADG (P = 0.43, 0.64, and 0.30, respectively; Table 4.3). Schmidt et al. (2013) found calves grazing on pastures of PM had an ADG of 0.56 kg/hd, while Burton (1970) suggested that PM could support gains up to 1 kg/d, indicating pastures of pearl millet may support adequate gains in summer grazing operations. Findings of Duckett et al. (2013) found steers grazing pastures of PM for the final 40 d in a forage finishing system gained 1.61 kg/d, which was higher compared to treatments of mixed pastures and alfalfa. While no statistical differences in ADG were found between treatment (P < 0.30), steers grazing pastures of BMR had a higher numerical value when compared to SS (1.10 kg/hd compared to 0.79 kg/hd, respectively), which may be attributed to the lower lignin content associated in forages with the brown midrib mutation. This mutation contributes to improved fiber digestion in the rumen (Sattler et al., 2010). Additionally, while no statistical differences were found in ADG or final BW between treatments of PMCG and PM, steers grazing treatments of PMCG had an ADG of 1.02 kg/hd, compared to steers grazing treatments of PM, which had an ADG of 0.87 kg/hd. This may be attributed to the high palatability and excellent nutritive value found in crabgrass (Blount et al., 2003; Dalyrmple et al., 1999; Ogden et al., 2006). However, a comparison of the chemical composition of PM and PMCG from this study shows no clear evidence of crabgrass consistently contributing to achieve a higher nutritive value throughout the grazing period. While serial ultrasound measurements (Table 4.3) for REA, 12th rib fat, percentage intramuscular fat and rump fat exhibited a day effect (P < 0.01), with values increasing for observed characteristics, no differences were found between treatment (P > 0.24).

Carcass Characteristics

No differences were found between steers finished on different forages for HCW (P = 0.85), dressing percentage (P = 0.36), REA (P = 0.62), 12th rib fat thickness (P = 0.31), KPH percent (P = 0.18), or yield grade (P = 0.52; Table 4.4). No differences in objective fat and lean color (Table 4.5; CIE L*, a*, b*), marbling (P = 0.12), firmness (P = 0.69), or texture (P = 0.14) were found between treatments. Cattle grazing treatments of SS exhibited more yellow fat color when compared to all other treatments (P < 0.01). No differences were found in skeletal maturity between all treatments (P = 0.19). Cattle which fall in the overall A maturity groups are classified with a live age of approximately 9-30 months of age, while cattle in B maturity groups are classified as approximately 30-42 months of age. Cattle with an A lean maturity have light cherry-red lean tissue, which has very fine lean texture. Cattle which have B lean maturity have light cherry-red to slight dark red lean tissue, which has a fine texture. These factors can provide indicators of the overall age of cattle, as the chronological age of cattle is often unknown. Cattle grazing treatments of PMCG had the greatest (P < 0.05) overall maturity score (A^{64}), which is due to cattle on PMCG having the greatest (P < 0.05) lean maturity score (B^{40}). Following PMCG, cattle grazing treatments of BMR had the greatest maturity score (A^{57}), followed by PM (A^{51}), which was similar to cattle grazing treatments of SS, which had an overall maturity score (A^{45}). These data indicate that cattle grazing PMCG would be classified as older than cattle grazing other treatments.

Proximate Analysis and Fatty Acids

An evaluation of steaks from steers finished on assigned treatments found no differences between treatments for moisture content (P = 0.21), N (P = 0.33), or percent lipid (P = 0.14; Table 4.6). An evaluation of fatty acid composition (Table 4.7) found steers grazing treatments of BMR to have a greater (*P* = 0.01) content of C 14:1. Additionally, samples from steers grazing BMR were found to have the greatest (*P* < 0.05) content of C 16:1, followed by SS, with cattle grazing treatments of PMCG and PM had the lowest content of C 16:1. No differences were found between treatment for total trans fatty acids (*P* = 0.27), total fatty acids (*P* = 0.28), total CLA (*P* = 0.74), saturated fatty acids (*P* = 0.30), monounsaturated fatty acids (*P* = 0.25), or polyunsaturated fatty acids (*P* = 0.78). While no differences were found between treatment for n:6 to n:3 ratio, all treatments had a ratio of less than 1.5:1. These values fall below the values recommended by healthcare professionals, which is recommended to be 4:1 or less (Simopoulos, 2008).

Sensory Analysis

Data from slice shear force found no difference (*P* = 0.36) in tenderness between treatment, which agreed with the sensory panel findings (*P* = 0.13; Table 4.8). Sensory panelists found no difference between treatment for juiciness (*P* = 0.71) or beef flavor intensity (*P* = 0.36). Treatments of BMR and SS had the greatest amount of off-flavor, followed by PM, with PMCG having the least amount of off-flavor, but were similar to PM. Although these may be statistically different, all treatments fall below levels of "Threshold off-flavor" and may not be biologically significant.

Shelf-life

An evaluation of lipid oxidation (Table 4.9) found no difference between the treatments (*P* = 0.66) throughout the study and did not exhibit a treatment by day interaction (*P* = 0.27).

Objective shelf life color evaluation of L*, a*, and b* revealed no treatment effect (*P* > 0.07) and did not exhibit a treatment by day interaction (*P* > 0.08). However, steaks from cattle grazing PMCG tended (*P* > 0.08) to be lighter than cattle grazing other treatments. No differences (*P* > 0.05) were found between treatments for chroma or ΔE, and did not exhibit a treatment by day interaction (*P* > 0.05). Hue exhibited a treatment by day interaction (*P* = 0.05), with lower values indicating a more red color. On d 1, SS had the greatest hue value, followed by PM and SS, with PMCG having the lowest value and appearing the most red in color. On d 3, PM had the greatest value for hue, followed by BMR, with PMCG and SS having the lowest hue, and therefore the most red steaks. On d 7, SS and BMR had the highest hue values, with PMCG being intermediate, and PM having the lowest values and presenting the most red color. Initially, myoglobin in fresh cut meat is in the form of deoxymyoglobin and is purple, forming the bright red color of oxymyoglobin when exposed to air, and oxygen is absorbed and allowed to bind to the iron in the heme ring within meat. Initially, cytochrome enzymes found within meat are able to reduce myoglobin and this reaction is reversible, maintaining equilibrium between deoxymyoglobin and oxymyoglobin, with a thin layer of metmyoglobin formed below the surface. As the reducing potential of cytochromes decreases over time and are no longer capable of maintaining the equilibrium, metmyoglobin formation increases, producing brown discoloration (Lawrie and Ledward, 2006). These data indicate cattle grazing SS may have an increased reducing potential found in their cytochromes, and are better able to maintain a more desirable red color, longer.

Subjective color evaluation found no treatment by day (*P* = 0.62) interactions or treatment effects (*P* = 0.96) for overall color. All treatments exhibited a day effect (*P* < 0.001), with steaks on d 7 appearing the darkest red, followed by d 5, followed by steaks on both d 0 and d 3, with steaks on d 1 having the brightest overall color. Subjective color evaluation for worst point color found no treatment by day (*P* = 0.09) interactions or treatment effects (*P* = 0.90). All treatments exhibited a day effect ($P < 0.01$), with worst point color similar on d 0 and 1, but increasing in all treatments as days of display increased. Subjective color evaluation found no difference between treatments in percent discoloration through d 3 of the study. On d 5, steaks from PM had the most discoloration compared to all other treatments. However, on d 7, steaks from PM had the least amount of discoloration when compared to other treatments. As muscle surfaces lose water and lead to an increased concentration of salts on the surface of meats, this may cause an increase in oxidation and a darkening and discoloration of lean tissue color (Lawrie and Ledward, 2007). These data suggest PM may have had less water loss, resulting in less water pooling on the surface, therefore resulting in a decrease in discoloration.

Implications

Specific forages in forage-finishing operations can affect carcass characteristics and shelf-life attributes. As a more yellow fat is indicative of forage-finished cattle, SS may be more desirable for use in forage-finished operations, as carcasses from cattle grazing SS had more yellow fat than cattle grazing other treatments. No difference in ADG or final BW indicated that these summer annual improved forages are of equal in value for use from an animal production standpoint. However, as steaks from cattle grazing PM had the least amount of discoloration on d 7, the use of this forage may aid in optimizing the shelf life. Additionally, as all steaks from treatments fell below levels of “threshold off-flavor” and may not be biologically detectable, any of these treatments may be of use with minimal effect on sensory aspects. These findings suggest these forage systems may have minimal affects on carcass and meat quality, as well as animal production when used in a forage finishing system.

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Table 4.1. Composition of Free-Choice Southern Piedmont Summer Beef Mineral for Beef Cattle on Pasture.

Mineral	Avg
Calcium (Ca)	14.70%
Phosphorus (P)	6.25%
Salt (NaCl)	14.05%
Magnesium (Mg)	1.0%
Cobalt (Co), ppm	10.00
Copper (Cu), ppm	1,200
Selenium (Se), ppm	26.00
Zinc (Zn), ppm	3,600
Vitamin A, IU per lb	80,000

Figure 4.1. Actual and normal (30-yr mean) precipitation from May through September 2013 at the University of Georgia J. Phil Campbell Sr. Research and Education Center near Watkinsville, Georgia; source: Georgia Automated Environmental Monitoring Network (2014).

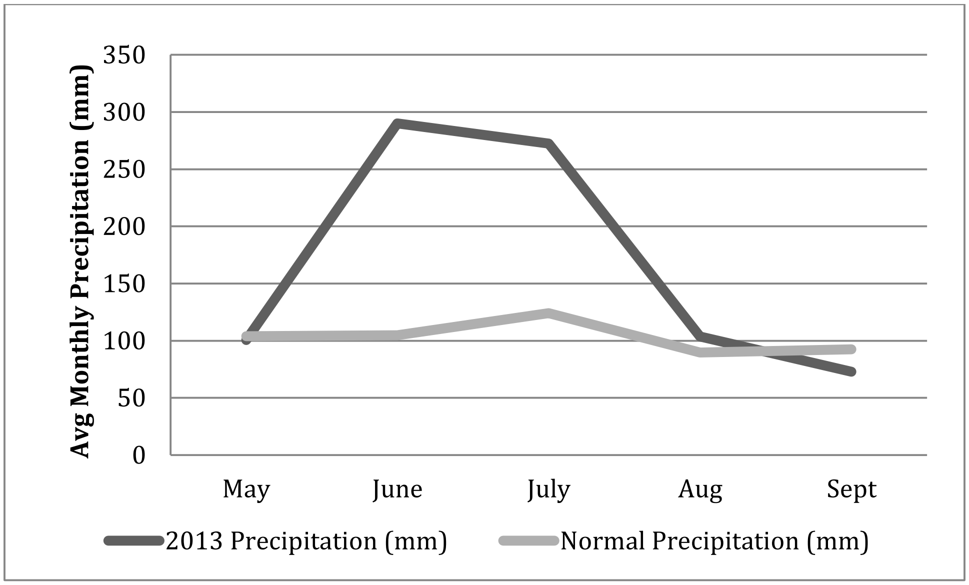

Figure 4.2. Actual and normal (30-yr mean) temperatures from May through September 2013 at the University of Georgia J. Phil Campbell Sr. Research and Education Center near Watkinsville, Georgia; source: Georgia Automated Environmental Monitoring Network (2014).

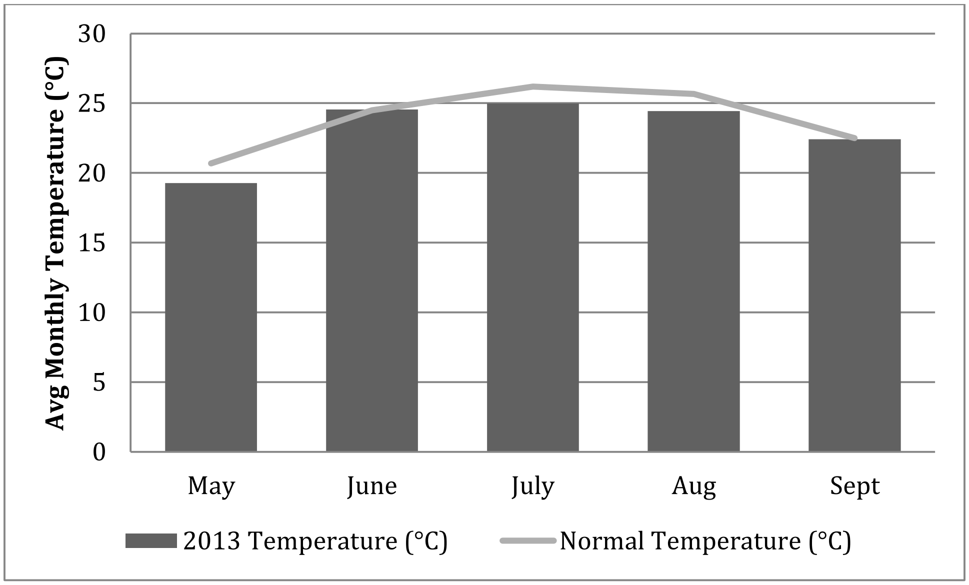

Table 4.2. Chemical composition and dry matter yields of forage sample mean (± SD) collected from June through September 2013.

Item/week	Forage			
	PMCG	PM	SS	BMR
	% DM basis			
Protein				
0	15.66 (1.4)	17.82 (1.1)	16.54 (0.9)	14.79 (1.0)
2	16.91 (1.2)	14.34 (0.8)	17.88 (0.2)	15.15 (1.4)
4	14.67 (1.7)	16.09 (0.5)	17.20 (1.4)	15.88 (1.4)
6	18.06 (1.4)	19.89 (1.3)	18.02 (1.1)	18.30 (1.3)
8	19.74 (1.9)	21.05 (2.1)	21.15 (2.0)	20.20 (1.3)
10	16.28 (1.6)	18.14 (1.2)	14.64 (0.6)	15.02 (0.7)
NDF				
0	59.43 (1.8)	58.71 (1.3)	59.74 (1.3)	60.22 (1.5)
2	60.00 (1.3)[b]	64.94 (0.9)[a]	58.32 (0.4)[b]	61.44 (1.8)[ab]
4	63.69 (2.0)[a]	61.58 (0.8)[ab]	56.76 (2.4)[c]	57.01 (1.0)[bc]
6	58.12 (1.7)	58.04 (1.5)	59.04 (1.5)	55.61 (1.4)
8	57.47 (2.8)	56.90 (2.3)	54.56 (1.7)	57.19 (1.5)
10	60.87 (1.2)[ab]	56.69 (1.6)[b]	61.71 (1.1)[a]	60.85 (2.0)[ab]
ADF				
0	34.79 (1.4)	34.42 (1.3)	36.04 (1.2)	35.13 (0.9)
2	35.38 (0.8)	37.86 (0.8)	33.55 (0.4)	35.27 (0.7)
4	36.03 (1.4)	33.64 (0.8)	33.81 (1.6)	32.19 (0.7)
6	34.90 (1.1)	34.03 (1.4)	35.42 (1.0)	34.76 (0.7)
8	33.40 (1.6)	31.90 (1.6)	32.5 (1.6)	33.04 (0.9)
10	34.36 (1.4)	31.38 (1.5)	35.28 (1.2)	35.35 (1.4)
TDN				
0	58.73 (1.6)	59.96 (1.8)	57.65 (1.6)	59.74 (0.7)
2	58.33 (1.0)[a]	54.20 (0.9)[b]	56.63 (0.6)[ab]	57.34 (1.1)[ab]
4	56.18 (1.0)[b]	57.86 (0.3)[ab]	58.73 (1.5)[ab]	60.93 (0.5)[a]
6	58.24 (1.3)[ab]	59.43 (1.2)[ab]	57.00 (0.9)[b]	60.72 (1.2)[a]
8	56.65 (1.6)	58.54 (1.5)	59.40 (1.1)	58.30 (1.6)
10	55.08 (1.6)[ab]	57.42 (1.2)[a]	52.19 (0.3)[b]	52.14 (1.7)[b]
RFQ[1]				
0	122.00 (7.7)[ab]	108.28 (10.2)[b]	113.71 (6.2)[b]	128.60 (2.8)[a]
2	115.10 (3.1)[ab]	102.87 (2.2)[b]	110.05 (2.7)[ab]	116.05 (5.0)[a]
4	110.52 (4.1)[b]	120.79 (2.4)[b]	118.91 (4.8)[b]	134.54 (4.5)[a]
6	110.33 (1.8)[ab]	107.40 (1.2)[ab]	105.33 (1.8)[b]	119.50 (2.8)[a]
8	97.41 (2.6)	99.07 (4.5)	100.11 (7.4)	103.55 (2.8)
10	106.88 (4.9)[ab]	115.75 (5.7)[a]	100.15 (2.1)[b]	99.70 (5.8)[b]
Yield, kg of DM/ha				
0	1314.15 (624)	830.20 (103)	1288.58 (320)	2445.34 (1379)
2	2217.13 (303)	2004.67 (237)	3474.23 (575)	3484.07 (1103)
4	2905.68 (566)	2640.10 (662)	1654.49 (420)	3651.29 (1690)
6	2175.82 (421)	1807.94 (115)	1804.00 (393)	1562.03 (349)
8	2087.23 (576)	1705.75 (71)	1373.12 (170)	1552.25 (246)

10	2452.55 (45)	2675.51 (247)	2238.78 (406)	1172.50 (346)

[ab]Least squares means within a row with different superscripts are different ($P < 0.05$).

[1]Relative forage quality; an index for ranking forages based on the intake of total digestible nutrients calculated by summative equations, after estimating digestible portions of protein, fatty acids, fiber, and non-fibrous carbohydrates (Allen et al., 2011).

Table 4.3. Least squares means of animal performance characteristics beef steers forage finished on pearl millet plus crabgrass (PMCG), pearl millet (PM), sorghum-sudangrass (SS) or brown midrib sorghum-sudangrass (BMR)

		Treatment					Effect		
Item		PMCG	PM	SS	BMR	SEM	Trt	Day	Trt*Day
Starting BW, kg		346.3	353.9	356.4	349.7	5.03	0.43		
Final BW, kg		430.9	426.4	421.7	441.2	13.24	0.64		
ADG, kg		0.95	0.87	0.79	1.10	0.15	0.30		
Gain/ha, kg		98.5	90.6	81.6	114.4	14.4	0.38		
Ultrasound data									
REA, cm^2	D0	52.4	53.8	52.7	52.7	1.92	0.93	<0.001	0.73
	D28	56.0	58.8	56.9	56.5	1.92			
	D56	57.3	57.2	60.5	57.3	1.92			
	D83	57.4	57.3	57.6	58.0	2.03			
12^{th} Rib Fat, cm	D0	0.2	0.2	0.3	0.3	0.04	0.24	<0.001	0.56
	D28	0.2	0.2	0.3	0.3	0.04			
	D56	0.3	0.3	0.3	0.4	0.04			
	D83	0.3	0.3	0.3	0.4	0.04			
IMF, %	D0	3.3	3.5	3.6	3.6	0.23	0.52	<0.001	0.50
	D28	3.2	3.4	3.6	3.7	0.25			
	D56	3.6	3.8	3.9	3.9	0.27			
	D83	3.6	3.8	3.9	4.1	0.30			
Rump Fat, cm	D0	0.5	0.5	0.4	0.5	0.06	0.63	<0.001	0.27
	D28	0.4	0.4	0.5	0.5	0.06			
	D56	0.5	0.5	0.6	0.7	0.06			
	D83	0.6	0.5	0.5	0.6	0.06			

Table 4.4. Least squares means of carcass yield characteristics for beef steers forage finished on pearl millet plus crabgrass (PMCG), pearl millet (PM), sorghum-sudangrass (SS) or brown midrib sorghum-sudangrass (BMR).

	Treatment				
Item	PMCG	PM	SS	BMR	SEM
HCW, kg	231.59	236.89	232.18	235.53	5.72
Dressing percent	53.76	55.79	55.08	53.49	1.20
Ribeye area, cm^2	57.58	63.47	60.81	60.40	3.38
12^{th} rib fat thickness, cm	0.26	0.20	0.20	0.37	0.09
Kidney, pelvic, heart fat, %	0.98	1.19	1.06	1.44	0.17
Calculated yield grade[a]	2.04	1.77	1.84	2.13	0.23

[a] *2.5 + (2.5 * fat thickness) + (.2 * %KPH) + (.0038 * hot carcass weight) - (.32 * ribeye area).*

Table 4.5. Carcass quality characteristics for beef steers forage finished on pearl millet plus crabgrass (PMCG), pearl millet (PM), sorghum-sudangrass (SS) or brown midrib sorghum-sudangrass (BMR).

	Treatment				
Item	PMCG	PM	SS	BMR	SEM
Obj. Lean Color					
L*[1]	32.59	32.63	33.85	33.34	0.79
a*[2]	19.86	19.87	20.57	20.39	0.98
b*[3]	5.96	5.75	6.59	6.07	0.53
Obj. Fat Color					
L*[1]	73.45	73.50	72.31	76.29	1.77
a*[2]	9.29	7.00	7.24	5.38	1.47
b*[3]	23.52	21.36	23.41	21.43	2.06
Subjective Lean Color[4]	5.69	5.25	4.88	5.13	0.34
Subjective Fat Color[5]	3.44[b]	3.13[b]	4.88[a]	2.50[b]	0.48
Marbling[6]	339.72	303.75	340.00	403.75	34.05
Firmness[7]	2.97	2.88	2.75	2.44	0.37
Texture[8]	2.19	1.50	1.50	1.75	0.25
Skeletal Maturity[9]	127.78	128.75	123.75	137.50	5.25
Lean Maturity[9]	240.00[a]	211.25[b]	198.75[b]	210.00[b]	8.36
Overall Maturity[9]	164.58[a]	151.25[bc]	145.00[c]	157.50[ab]	4.11

[ab]Least squares means within a row with different superscripts are different ($P < 0.05$).

[1]0 = Black, 100 = White.

[2]Measurement of green to red; a higher value indicates increased redness.

[3]Measurement of blue to yellow; a higher value indicates increased yellowness.

[4]1 = Extremely dark red, 2 = Dark red, 3 = Moderately dark red, 4 = Slightly dark cherry red, 5 = Slightly bright cherry red, 6 = Moderately bright cherry red, 7 = Bright cherry red, 8 = Extremely bright cherry red.

[5]1 = White, 2 = Creamy white, 3 = Slightly yellow, 4 = Moderately yellow, 5 = Yellow.

[6]100 = Practically devoid, 200 = Traces, 300 = Slight, 400 = Small, 500 = Modest, 600 = Moderate, 700 = Slightly abundant, 800 = Moderately abundant.

[7]1 = Very firm, 2 = Firm, 3 = Slightly firm, 4 = Slightly soft, 5 = Soft.

[8]1 = Very fine, 2 = Fine, 3 = Slightly fine, 4 = Slightly coarse, 5 = Coarse.

[9]100 = A, 200 = B, 300 = C, 400 = D, 500 = E.

Table 4.6. Least squares means for proximate analysis of steaks from beef steers forage finished on pearl millet plus crabgrass (PMCG), pearl millet (PM), sorghum-sudangrass (SS) and brown midrib sorghum-sudangrass (BMR).

	Treatment				
Item	PMCG	PM	SS	BMR	SEM
Moisture[1], %	73.37	74.45	74.09	73.36	0.49
N, %	14.12	14.39	14.19	13.94	0.20
Lipid[2], %	1.91	1.66	1.91	2.49	0.29

[1]AOAC, 1990.

[2]Folch et al., 1957.

Table 4.7. Fatty acid composition of steaks from steer forage finished on treatments of pearl millet plus crabgrass (PMCG), pearl millet (PM), sorghum-sudangrass (SS), or brown midrib sorghum-sudangrass (BMR).

	Treatment				
Fatty Acid, mg FA/g lipid	PMCG	PM	SS	BMR	SEM
Saturated Fatty Acids					
C 8:0	0.00	0.00	0.00	0.00	0.00
C 10:0	0.00	0.00	0.00	0.00	0.00
C 12:0	0.03	0.03	0.03	0.04	0.00
C 13:0	0.10	0.00	0.00	0.00	0.05
C 14:0	0.82	0.84	1.02	1.44	0.22
C 15:0	0.19	0.18	0.23	0.24	0.04
C 16:0	9.83	9.05	11.24	14.38	2.17
C 17:0	0.48	0.44	0.58	0.57	0.11
C 18:0	6.52	5.77	7.91	8.39	1.53
C 20:0	0.00	0.02	0.00	0.00	0.02
C 21:0	0.00	0.03	0.03	0.11	0.06
C 22:0	0.01	0.01	0.02	0.03	0.01
Monounsaturated Fatty Acids					
C 14:1	0.14^{b}	0.15^{b}	0.19^{b}	0.31^{a}	0.04
C 16:1	1.16^{b}	1.02^{b}	1.41^{ab}	1.92^{a}	0.25
C $18{:}1^{trans\text{-}9}$	0.13	0.12	0.15	0.17	0.03
C $18{:}1^{trans\text{-}11}$	1.25	1.08	1.71	1.58	0.37
C $18{:}1^{cis\text{-}9}$	14.45	12.55	16.64	19.67	3.09
C $18{:}1^{cis\text{-}11}$	0.43	0.41	0.54	0.64	0.08
Polyunsaturated Fatty Acids					
C $18{:}2^{cis\text{-}9,\ cis\text{-}12}$	1.18	1.22	1.29	1.27	0.11
C $18{:}3^{cis\text{-}9,\ cis\text{-}12,\ cis\text{-}15}$	0.50	0.51	0.59	0.59	0.07
C $18{:}2^{cis\text{-}9,\ trans\text{-}11}$	0.26	0.21	0.31	0.33	0.06
C $18{:}2^{cis\text{-}11,\ trans\text{-}13}$	0.00	0.01	0.00	0.00	0.00
C $18{:}2^{,trans\text{-}10,\ cis\text{-}12}$	0.01	0.00	0.00	0.01	0.00
C $18{:}2^{cis\text{-}11,\ cis\text{-}13}$	0.02	0.01	0.02	0.03	0.00
C $18{:}2^{cis\text{-}10,\ cis\text{-}12}$	0.00	0.00	0.01	0.01	0.00
C $18{:}2^{trans\text{-}9,trans\text{-}11}$	0.09	0.08	0.11	0.14	0.02
C $20{:}4^{cis\text{-}5,\ 8,\ 11,\ 14}$	0.45	0.48	0.46	0.46	0.04
C $20{:}5^{cis\text{-}5,\ 8,\ 11,\ 14,\ 17}$	0.27	0.33	0.31	0.29	0.03
C $22{:}5^{cis\text{-}7,\ 10,\ 13,\ 16,\ 19}$	0.35	0.38	0.36	0.36	0.03
C $22{:}6^{cis\text{-}4,\ 7,\ 10,\ 13,\ 16,\ 19}$	0.04	0.04	0.04	0.04	0.01
Sums of fatty acid types					
SFA[1]	17.97	16.37	21.06	25.06	4.03
MUFA[2]	17.56	15.33	20.65	24.89	3.80
PUFA[3]	3.16	3.28	3.50	3.52	0.32
CLA[4]	1.98	2.06	2.21	2.26	0.22
n-3[5]	1.16	1.26	1.31	1.28	0.12
n-6[6]	1.63	1.70	1.75	1.73	0.13
Comparison of fatty acid ratios					

MUFA : PUFA	1.00	0.92	1.00	0.97	0.03
PUFA : SFA	0.22	0.23	0.20	0.15	0.03
UFA : SFA	1.22	1.15	1.20	1.14	0.05
n-6: n-3	1.39	1.35	1.36	1.37	0.05

[ab]Least squares means within a row with different superscripts are different ($P < 0.05$).

[1]SFA = Saturated fatty acids; summation of SFA including C 8:0, C 10:0, C 12:0, C 13:0, C 14:0, C 15:0, C 16:0, C 17:0, C 18:0, C 20:0, C 21:0, and C 22:0.

[2]MUFA= Monounsaturated fatty acids; summation of MUFAs including C 14:1, C 16:1, C 18:1$^{trans\text{-}9}$, C 18:1$^{trans\text{-}11}$, C 18:1$^{cis\text{-}9}$, and C 18:1$^{cis\text{-}11}$.

[3]PUFA = Polyunsaturated fatty acids; summation of PUFAs including C 18:2$^{cis\text{-}9, 12}$, C 18:3$^{cis\text{-}9, 12, 15}$, C 18:2$^{cis\text{-}9,trans\text{-}11,}$ C 18:2$^{cis\text{-}11,trans\ 13}$, C 18:2$^{trans\text{-}10,cis\text{-}12}$, C 18:2$^{cis\text{-}11,13}$, C 18:2$^{cis\text{-}10,\ 12}$, C 18:2$^{trans\text{-}9,\ 11}$, C 20:4$^{cis\text{-}5,\ 8,\ 11,\ 14}$, C 20:5$^{cis\text{-}5,\ 8,\ 11,\ 14,\ 17}$, C 22:5$^{cis\text{-}7,\ 10,\ 13,\ 16,\ 19}$, and C 22:6$^{cis\text{-}4,\ 7,\ 10,\ 13,\ 16,\ 19}$.

[4]Summation of CLA isomers including C 18:2$^{cis\text{-}11,\ trans\text{-}13}$, C 18:2$^{,trans\text{-}10,\ cis\text{-}12}$, C 18:2$^{cis\text{-}10,\ cis\text{-}12}$, *and* C 18:2$^{trans\text{-}9,\ 11}$.

[5]Summation of n-3 fatty acids including C18:3$^{cis\text{-}9,12,15}$,C20:5$^{cis\text{-}5,8,11,14,17}$, C22:5$^{cis\text{-}7,\ 10,\ 13,16,\ 19}$ and C22:6$^{cis\text{-}4,\ 7,\ 10,\ 13,16,\ 19}$.

[6]Summation of n-6 fatty acids including C18:2$^{cis\text{-}9,\ 12,}$ and C20:4$^{cis\text{-}5,8,11,14}$.

Table 4.8. Least squares means for sensory and cooking characteristics for beef steers forage finished on pearl millet plus crabgrass (PMCG), pearl millet (PM), sorghum-sudangrass (SS) or brown midrib sorghum-sudangrass (BMR).

	Treatment				
Item	PMCG	PM	SS	BMR	SEM
Sensory Characteristics					
Overall Tenderness[1]	3.49	4.99	5.05	4.81	0.53
Overall Juiciness[2]	4.17	4.55	4.63	4.50	0.31
Beef Flavor Intensity[3]	5.13	5.10	4.83	5.18	0.18
Off-Flavor[4]	1.00[b]	1.28[ab]	1.43[a]	1.61[a]	0.14
Slice Shear Force, kgf	32.39	22.47	22.79	21.35	0.41
Cooking Characteristics					
Thaw Loss, %	3.26	3.12	2.46	2.47	0.48
Cook Loss, %	17.33	14.76	12.93	14.06	1.39

[ab]Least squares means within a row with different superscripts are different (P < 0.05).

[1]8 = Extremely tender, 7 = Very tender, 6 = Moderately tender, 5 = Slightly tender, 4 = Slightly tough, 3 = Moderately tough, 2 = Very tough, 1 = Extremely tough.

[2]8 = Extremely juicy, 7 = Very juicy, 6 = Moderately juicy, 5 = Slightly juicy, 4 = Slightly dry, 3 = Moderately dry, 2 = Very dry, 1 = Extremely dry.

[3]8 = Extremely intense, 7 = Very intense, 6 = Moderately intense, 5 = Slightly intense, 4 = Slightly bland, 3 = Moderately bland, 2 = Very bland, 1 = Extremely bland.

[4]6 = Extreme off-flavor, 5 = Very strong off-flavor, 4 = Moderate off-flavor, 3 = Slight off-flavor, 2 = Threshold off-flavor, 1 = None detected.

Table 4.9. Shelf-life data for beef steers forage finished on pearl millet plus crabgrass (PMCG), pearl millet (PM), sorghum-sudangrass (SS) or brown midrib sorghum-sudangrass (BMR).

Item		Treatment				SEM	Effect		
		PMCG	PM	SS	BMR		Trt	Day	Trt*Day
TBARS[1]	D0	0.14	0.12	0.12	0.14	0.01	0.66	<0.0001	0.27
	D1	0.15	0.14	0.13	0.13	0.01			
	D3	0.17	0.15	0.14	0.15	0.02			
	D5	0.17	0.17	0.20	0.20	0.03			
	D7	0.18	0.15	0.20	0.17	0.02			
Color									
*Lean L**[2]	D0	30.85	30.38	29.44	29.01	2.17	0.07	<.0001	0.08
	D1	31.88	46.78	51.44	36.31	6.13			
	D3	8.92	15.97	8.65	9.51	1.94			
	D5	21.39	22.10	19.66	21.79	3.10			
	D7	11.83	20.51	20.12	19.14	6.26			
*Lean a**[3]	D0	29.35	28.77	28.38	27.75	1.38	0.54	<.0001	0.40
	D1	26.69	26.28	26.17	27.60	2.68			
	D3	13.31	17.68	12.82	13.13	2.18			
	D5	17.17	13.93	14.40	15.88	2.02			
	D7	10.59	15.45	12.00	12.96	2.06			
*Lean b**[4]	D0	23.75	22.71	22.27	21.96	1.47	0.66	<.0001	0.19
	D1	20.16	22.42	22.23	21.73	1.28			
	D3	7.89	12.72	7.60	8.28	2.03			
	D5	12.87	10.97	11.01	12.09	1.91			
	D7	7.51	9.38	9.17	9.38	1.75			
Hue[5]	D0	38.96	38.38	37.81	38.38	0.57	0.75	<.0001	0.05
	D1	37.24	41.25	41.82	38.38	2.29			
	D3	30.36	34.95	30.36	31.51	1.15			
	D5	36.09	38.38	37.24	37.24	1.72			
	D7	35.52	30.94	36.09	36.09	2.86			
Chroma[6]	D0	37.76	36.66	36.09	35.39	1.99	0.58	<.0001	0.35
	D1	33.44[b]	34.70[ab]	34.47[a]	35.13[ab]	2.72			
	D3	15.48[b]	21.80[a]	14.92[b]	15.54[ab]	2.95			
	D5	21.47	17.76	18.17	20.00	2.75			
	D7	13.06[ab]	18.11[b]	15.17[a]	16.14[a]	2.55			
ΔE[7]	D1	10.14	18.45	23.02	10.43	6.53	0.31	<.0001	0.19
	D3	31.50	22.83	29.89	28.00	4.03			
	D5	19.55	21.56	20.77	17.39	5.13			
	D7	31.71	22.14	26.79	24.69	5.48			

[ab]Least squares means within a row with different superscripts are different ($P < 0.05$).

[1]Values reported in mg MDA/kg meat.

[2]0 = Black, 100 = White.

[3]Measurement of green to red; a larger value indicates increased redness.

[4]Measurement of blue to yellow; a larger value indicates increased yellowness.

[5]Lower value indicates a more red color.

[6]Higher value indicates more red saturation.

[7]Change in color over time.

CHAPTER 5

CONCLUSIONS AND IMPLICATIONS

With traditional feed prices reaching record highs in recent years, opportunity lies in increasing body weight of feeder calves economically on high quality forages, such as cool season annuals, prior to entering a finishing program. Cattle grazing treatments of rye plus ryegrass were shown to gain a greater amount of BW in two of three years. Additionally, during years when temperatures were cooler and precipitation was abundant, rye plus arrowleaf and crimson clover was able to sustain a greater amount of BW gained. These data indicate either of these forage combinations may be ideal for use in Southeast stocker cattle production systems.

Additionally, with the growing interest in forage-finished beef product, there has been a renewed interest in finding forages which are able to withstand the potentially harsh summer months in the Southeast while providing adequate gains. This research has shown that forage systems of pearl millet, pearl millet plus crabgrass, sorghum-sudangrass, or brown midrib sorghum-sudangrass may successfully be used in forage-finished operations. More yellow fat is indicative of forage-finished beef and, because of its appeal to some consumers, this may be more desirable in forage-finished beef producers. Utilizing sorghum-sudangrass may be ideal in these operations, as meat from cattle grazing this forage was shown to have more yellow fat. However, as there were no differences found in animal performance, carcass yield or quality characteristics, or sensory characteristics, any of these forage systems may be used in a forage-finishing operation.